

PATIENT-SPECIFIC IMPLANT DESIGN AND MANUFACTURING SYSTEM WITH A DIGITAL FILING CABINET MANAGER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application No.: 63/313,638, filed February 24, 2022, U.S. Provisional Patent Application No.: 63/313,620, filed February 24, 2022, and U.S. Provisional Patent Application No.: 63/313,602, filed February 24, 2022, the disclosures of which are incorporated by reference herein in their entireties.

TECHNICAL FIELD

[0002] The present disclosure is generally related to storing medical records, and more particularly to systems and methods for storing and accessing healthcare data in digital filing cabinets.

BACKGROUND

[0003] Numerous types of data associated with patient treatments and records are available. To locate a patient's medical records and health history, physicians often rely on collecting information from the patient at the time of a healthcare appointment or patient data available via the patient's medical record. However, patient data may not be readily available or up to date, or the patient may be unconscious due to, for example, an accident. For example, it is often difficult to obtain information (e.g., manufacturing information, surgical procedure used, etc.) related to surgical implants. Accordingly, conventional methods for collecting and updating patient medical records may lack necessary information for an accurate assessment of a patient's health.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The accompanying drawings illustrate various embodiments of systems, methods, and embodiments of various other aspects of the disclosure. Any person with ordinary skill in the art will appreciate that the illustrated element boundaries (e.g., boxes, groups of boxes, or other shapes) in the figures represent one example of the boundaries. It may be that in some examples one element may be designed as multiple elements or that multiple elements may be designed as one element. In some examples, an element

shown as an internal component of one element may be implemented as an external component in another, and vice versa. Furthermore, elements may not be drawn to scale. Non-limiting and non-exhaustive descriptions are described with reference to the following drawings. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating principles.

[0005] FIG. 1 is a network connection diagram illustrating a system for providing patient-specific medical care, according to an embodiment.

[0006] FIG. 2 illustrates a computing device suitable for use in connection with the system of FIG. 1, according to an embodiment.

[0007] FIG. 3 is a system diagram illustrating an example of a computing environment in which the disclosed system operates in some embodiments.

[0008] FIG. 4 is a block diagram illustrating components which, in some implementations, can be used in a system employing the disclosed technology.

[0009] FIG. 5 is a flow diagram illustrating a process used in some implementations for providing patient-specific healthcare data from an implant.

[0010] FIG. 6 is a flow diagram illustrating a process used in some implementations for analyzing patient-specific healthcare data from an implant.

[0011] FIG. 7 is a flow diagram illustrating a process used in some implementations for managing patient-specific healthcare data by a healthcare provider.

[0012] FIGS. 8A and 8B illustrate an exemplary virtual model of a patient's spine that may be used and/or generated in connection with the methods described herein, according to an embodiment.

[0013] FIG. 8C illustrates an exemplary patient data set that may be used in connection with the methods described herein, according to an embodiment.

[0014] FIGS. 9A-1-9B-2 illustrate an exemplary virtual model of a patient's spine in a pre-operative anatomical configuration and a corrected anatomical configuration. More specifically, FIGS. 9A-1 and 9A-2 illustrate the pre-operative anatomical configuration of the patient, and FIGS. 9B-1 and 9B-2 illustrate the corrected anatomical configuration.

[0015] FIG. 10A illustrates an exemplary interactive surgical plan for a patient-specific surgical procedure, according to an embodiment.

[0016] FIG. 10B illustrates an exemplary interactive user interface to access patient information, according to an embodiment.

[0017] FIG. 11 illustrates an exemplary surgical plan report detailing the surgical plan for surgeon review and for use in connection with the methods described herein, according to an embodiment.

[0018] FIGS. 12A and 12B illustrate an exemplary patient-specific implant that can be used and/or generated in connection with the methods described herein, according to an embodiment.

[0019] FIG. 13 illustrates a segment of a patient's spine after several patient-specific implants have been implanted therein.

DETAILED DESCRIPTION

[0020] The present technology is directed to systems and methods for storing, managing, and accessing healthcare data in digital filing cabinets. For example, in many embodiments, the present technology is directed to providing healthcare data from an implant, such as a patient-specific implant. The system can receive and store patient healthcare data from a source (e.g., wearable device, implant, healthcare provider device, etc.). The system can manage access to the healthcare data based on authentication levels. The authentication levels can include, without limitation, authenticating a user based on geolocation, biometric data, blockchain, tokens, or any authentication method. Based on the determined authentication level of the user requesting access to the healthcare data on the implant, the system can permit the user to access some or all of the healthcare data. The system can include one or more healthcare digital filing cabinets that store healthcare data, patient information, electronic medical records, and/or additional patient related information. In some embodiments, systems can share data (e.g., healthcare data, patient information, electronic medical records, and/or additional patient related information) via a network without using digital filing cabinets. The digital filing cabinets can use blockchain and non-fungible token (NFT) technology to control collection and access to the EMRs.

[0021] In some embodiments, the present technology is directed to analyzing patient-managed healthcare data. An analytics system can analyze healthcare data collected from wearable devices, an implant, patient devices, healthcare provider

devices, databases, cloud storage accounts, healthcare databases, or digital filing cabinets (e.g., patient digital filing cabinets, healthcare digital filing cabinets, etc.). The analytics system can identify health goals in the healthcare data and determine if the health metrics collected by the wearable devices or implant are within a health range. When the health metrics are not within the health range, the analytics system generates a notification to alert the patient of the health risks and provide guidance (e.g., diet suggestions, exercise routines, pharmacological suggestions, etc.). In some embodiments, the analytics system generates notifications for the patient's physician, family member, etc.

[0022] The healthcare data can be managed using one or more digital filing cabinets. A user can approve family members, physicians, healthcare providers, or other users to access selected data, types of data, data associated with the procedure, data associated with the user, or the like. An access control list can be managed by the user to manage access rights. The access control list may be stored in a database or in a digital filing cabinet. The digital filing cabinet can contain, for example, containerized data, surgical plans, virtual models (e.g., virtual anatomical models, virtual implant models, etc.), implant data, health records, medical insurance information, medical imaging, digital wallets, and other healthcare data. The containerized data can include access control settings matching available settings for the access control list. For control list or authorization level synchronization, containerized data can be synchronized with other containerized data based on authorization levels or control lists, thereby synchronizing surgical plans viewable by multiple users. In some embodiments, the surgical plans for patients may have different amounts of information than surgical plans for health care providers, such as surgeons or surgical teams.

[0023] In some implementations, the digital filing cabinet can automatically update the healthcare data based on received data. In some implementations, the digital filing cabinet can automatically receive data from user devices, such as wearable devices, smartphones, or other devices capable of collecting biometrics of the user. The user's digital filing cabinet can link one or more accounts to provide communication between the accounts. For example, the accounts can be healthcare provider accounts, family member accounts, insurance provider accounts, government entity accounts, or other accounts that allow the digital filing cabinet to request and receive data. The user can manage third-party access (e.g., viewing only, editing, annotation, etc.) of the stored data.

This allows the user to authorize, for example, a physician access to view data collected in real-time or almost real-time. The physician can provide real-time or almost real-time feedback to the patient via the digital filing cabinet. The patient can use the digital filing cabinet or a patient account to, for example, review physician feedback, a diagnosis, a treatment plans (e.g., a surgical plan, interventional plan, therapy plan, etc.), predicted treatment outcomes, cost estimates, insurance information, or the like.

[0024] In some embodiments, the present technology is directed to managing patient-specific healthcare data by a healthcare provider. A data management system can manage patient healthcare data by collecting patient healthcare data and generating health goals for the patient based on the healthcare data. The data managing system can generate viewable versions of the healthcare data for the patient to view on a user interface. For example, the managing system can generate graphs to illustrate a patient's health metrics or provide the patient with medical images, such as x-ray images, CT scans, MRI scans, etc.

[0025] The data management system can generate alerts based on events from data inputted into the digital filing cabinet. The notifications can be, for example, physician notifications, user notifications, family member notifications or other notifications generated based on monitoring data from wearables, requests for updated information, or the like. In response to notification generation, the data management system can schedule appointments, notify healthcare providers of adverse events, predict adverse events (e.g., predicted emergencies), or the like. The data management system can lock digital filing cabinets in response failed authorization attempts, notify users of potential fraudsters, etc.

[0026] The data management system can analyze collected data to generate post-treatment plans. In some embodiments, the data managing system can use one or more models to analyze post-operative collected data to generate or modify post-treatment plans, such as therapy plans, new surgical plans, etc. Post-operative analytics can be stored in the digital filing cabinets or other databases. This allows the data management system to periodically or continuously analyze data from different data sources to provide patient-specific healthcare. The data management system can select a model (e.g., machine learning model) selected based on the available data. If new data comes available, the data management system can identify one or more models suitable for

analyzing the newly available data. This allows the data management system to adaptively select machine learning models to enhance analytics. The data sources can include, without limitation, diagnostic equipment (e.g., imaging equipment), patient wearables, hospital diagnostic equipment, etc.

[0027] In some embodiments, a healthcare management system includes digital filing cabinets that integrate data from, for example, digital wallets, one or more devices associated with the user, or data sources associated with a physician/healthcare provider. The healthcare management system can generate post-operative analytics based on post-operative data, such as new scans of the patient, diagnostic data, new patient medical records, or the like can be used. The healthcare management system can manage authentication, patient wallets, and/or digital filing cabinets via, for example, automated settings, privacy management, updated record management, etc.

[0028] In some embodiments, point of care devices can be integrated with a healthcare management system. Data from the point of care devices can be automatically transmitted to the patient's digital filing cabinet. This allows patient access the digital filing cabinets (e.g., implant manufacture managed digital filing cabinets, healthcare provider managed digital filing cabinets, etc.) and view and/or manage data in real-time or almost real-time.

[0029] Without being bound by theory, using a healthcare data management platform to perform various aspects of the surgical plans described herein is expected to provide several advantages over conventional operative techniques. For example, storing, analyzing, managing, and accessing healthcare data in digital filing cabinets may improve data security of patient information, decrease patient recovery time by giving them access to health metrics and areas to improve, decrease patient stress for pre-procedures and post procedures by having access to medical information (e.g., x-ray images, procedure routines, pre-op instructions, post-op instructions, etc.), shorten analysis/assessment time of patients because healthcare providers can access the patients information in real-time or almost real-time from the patient's implant, and alert the patient and healthcare providers of implant updates or recalls from the implant manufacturer.

[0030] In representative embodiments, the foregoing method can be performed by a system storing computer-executable instructions that, when executed, cause the system to perform the steps of the method.

[0031] In some embodiments, a computer-implemented method includes linking to a patient-managed account storing patient data associated with a patient-specific implant. The method includes receives patient data from a patient-managed account. The received patient data is analyzed to identify a relevant training parameter. A reference data set is generated based on the relevant training parameter. The machine learning models are trained based at least in part on the reference data set for designing implants similar to the patient-specific implant. In some embodiments, the relevant training parameter can be a categorized spinal condition, wherein the categorization is based on one or more predetermined thresholds. The predetermined thresholds can include a threshold level-specific lumbar lordosis, a threshold Cobb angle, a threshold pelvic incidence, and/or a threshold disc height. In some embodiments, the received patient data includes at least one of comparing the received patient data to preoperative data of the patient or identifying at least a portion of the patient data for the reference data set based on the comparison. Embodiments of the present disclosure will be described more fully hereinafter with reference to the accompanying drawings in which like numerals represent like elements throughout the several figures, and in which example embodiments are shown. Embodiments of the claims may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. The examples set forth herein are non-limiting examples and are merely examples among other possible examples.

[0032] The words “comprising,” “having,” “containing,” and “including,” and other forms thereof, are intended to be equivalent in meaning and be open ended in that an item or items following any one of these words is not meant to be an exhaustive listing of such item or items, or meant to be limited to only the listed item or items.

[0033] As used herein and in the appended claims, the singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise.

[0034] Although the disclosure herein primarily describes systems and methods for storing and accessing healthcare data in a digital filing cabinet associated with an implant, plan (e.g., surgical plan, treatment plan, etc.), the technology may be applied

equally to medical treatment and devices in other fields (e.g., other types of medical practices) with or without utilizing digital filing cabinets. Additionally, although many embodiments herein describe systems and methods with respect to implanted devices, the technology may be applied equally to other types of medical technologies and devices (e.g., non-implanted devices).

[0035] FIG. 1 is a network connection diagram illustrating a computing system 100 for storing and accessing healthcare data in digital filing cabinets, according to an embodiment. As described in further detail herein, the system 100 is configured to collect, store, monitor, and/or update healthcare data. System 100 can include one or more digital filing cabinets 180 that can contain, without limitation, one or more electronic health records (EHRs), EMRs, patient information, digital wallets (e.g., tokens, credit cards, crypto currency, payment information, etc.), and other healthcare data. The digital filing cabinet 180 can receive and convert the healthcare data into a digital format to increase efficiency of locating and retrieving healthcare data. The digital filing cabinet 180 can receive the healthcare data from a patient, healthcare provider(s), medical insurance entities, banking entities, imaging centers, and/or storage devices with healthcare data. Based on the type of healthcare data, the digital filing cabinet 180 can organize the healthcare data by authentication levels. For example, the patient can access all the healthcare data, but the healthcare provider is limited to medical records and cannot access the patient's medical insurance or payment information. The digital filing cabinet 180 contains the patient healthcare data 108 and organizes the patient healthcare data by different authentication levels, such as data 108a, 108b, 108c, and 108d. Each group or set of healthcare data 108a, 108b, 108c, and 108d requires a different level of authentication for a user to access. Example healthcare datasets and healthcare data are discussed in connection with FIGS. 8-11. Once the authentication level of a user is identified, the system 100 can send the healthcare data associated with the identified authentication level to the user. In some implementations, the system 100 sends the healthcare data to the patient's implant 150 (e.g., distributed ledger enabled medical implant, blockchain-enabled medical implant, etc.) for the user to retrieve and/or to a user device. The implant 150 can include memory storage to store the healthcare data. The implant 150 can include wireless communication devices, such as one or more chips (e.g., Bluetooth chips or Near Field Communication (NFC) chips), so that a user device can wirelessly receive the healthcare data from the implant 150. The implant 150

can transmit the healthcare data in an encrypted format and the user can decrypt the healthcare data. In some implementations, computing system 100 can generate and transmit a code (e.g., quick response code (QR code), identifier (e.g., via radio-frequency identification (RFID)), or identification the user can scan to access healthcare data on the implant 150.

[0036] The number of groups of healthcare data, permission settings, stored data, organizational scheme, and/or other configurations can be set by the user, healthcare provider, or the like. Data can be automatically collected and incorporated into the appropriate group of data. In cloud-based implementations, the digital filing cabinet 180 can be stored on a cloud server to provide remote access. In some implementations, the digital filing cabinet 180 can be stored locally to provide access to records at any time. Additionally, local storage of the digital filing cabinets 180 with digital wallets containing blockchain information can be stored locally. Each group of healthcare data 108a, 108b, 108c, and 108d can be associated by the user (or data management system) with, for example, a procedure, a physician, a healthcare provider, and/or medical manufacture. The user can add information, including annotation, personal notes, and other information that may or may not be viewable by other users, to the healthcare data 108a, 108b, 108c and 108d and can select the type, amount, and/or level of authorization/access.

[0037] In some embodiments, a group of healthcare data 108a can be associated with an implant 150 in the patient (not shown) and can include a surgical plan for the implant 150, manufacturing data for the implant 150, notifications (e.g., recall notifications), predicted post-treatment analytics, physician information, and other information (e.g., pre-operative, intra-operative, and/or post-operative information) associated with the implant 150 or procedure. The user can set one or more rules for allowing authorized user(s) to access (e.g., all or a portion of) the healthcare data 108a or healthcare data 108. For example, the user can authorize viewing of post-operative data 108a by a physical therapist who can access post-operative collected data to modify therapy plans for the user. The user can authorize a primary care physician access to the healthcare data 108 to provide general healthcare treatment and can authorize a surgeon access to the healthcare data 108a to evaluate surgical outcomes and recommend additional treatments, such as future surgical interventions.

[0038] The healthcare data 108b can include, for example, general electronic medical records (EMRs) of the patient, including health records not associated with the implant. The user can authorize a primary care physician access to the healthcare data 108b to provide general healthcare treatment. The user can authorize family members and third parties access to the healthcare data 108b. Accordingly, the access settings for the healthcare data 108a, 108b can be the same or different.

[0039] The healthcare data 108c can include, for example, data from a user device input. The data can be from, for example, wearables (e.g., smartwatches, pedometers, etc.), smartphones, biometric sensors (e.g., analyte sensors, glucose sensors, etc.), heart monitors, exercise monitoring equipment, or the like. The user can authorize family members to access the data 108c to help with compliance with, for example, dietary goals, exercise goals, or other user goals.

[0040] Data can be automatically provided to the digital filing cabinet 180. In some embodiments, for example, an implant retrieval feature 160 can provide instructions for accessing the digital filing cabinet 180. An imaging apparatus (e.g., an MRI machine, x-ray machine, scanner, etc.) can read information from the retrieval feature 160. The information can be transmitted, via communication network 104, to the digital filing cabinet 180. The transmitted information can include, without limitation, authorization information (e.g., digital filing cabinet login information), patient identification, implant identifier, patient imaging, and/or other information to use to authorize, locate, and/or categorize data.

[0041] The digital filing cabinet 180 can store data transmitted, via the communication network 104, from manufacturing system 124 and can analyze received data and correlate the data, such as manufacturing data, with the received implant data. Correlation settings can be modified or set by the user. Additionally, surgical plans can be transmitted, via the communication network 104, from the system 106 to the digital filing cabinet 180. The surgical plan can be associated with the manufacturing data, implant data, and other information associated with the implant 150. The digital filing cabinet 180 can send, via the communication network 104, patient healthcare data to the system 106. This allows newly available data to be automatically or periodically transmitted to the analysis system 106. The analysis system 106 can analyze the newly received data using, for example, one or more models to provide analytics to the client

computing device 102, digital filing cabinet 180, manufacturing system 124, physician, etc. The client computing device 102 can receive analytics and notifications from, for example, the digital filing cabinet 180, analysis system 106, and/or other data source.

[0042] In some embodiments, the system 100 is configured to manage patient healthcare data on user devices, cloud-based devices, and/or healthcare provider devices. The healthcare data can include patient medical records, medical insurance information, health metrics from wearable devices, surgical information, surgical plans, technology recommendations (e.g., device and/or instrument recommendations), and/or medical device information (e.g., an implanted medical device (also referred to herein as an “implant” or “implanted device”) or implant delivery instrument). The digital wallet can be used to manage blockchain healthcare data (e.g., blockchain EHRs, EMRs, etc.), insurance actions (e.g., payments, claim submissions, etc.), or the like.

[0043] In some embodiments, the system 100 manages the authentication required to access the medical records. The authentication can include blockchain, tokens, keys, biometrics, geolocation, passwords, or any authentication credentials. Healthcare data that is particular to a patient, is referred to herein as a “patient-specific” or “personalized” healthcare data. The digital filing cabinet 180 can store one or more keys (e.g., private keys, public keys, etc.), authentication information, and/or other information for accessing data, including electronic medical records associated with a patient from a distributed blockchain ledger of electronic medical records. U.S. Application No. 17/463,054 discloses systems and methods for tracking patient medical records using, for example, keys and is incorporated by reference in its entirety. The system 100 can include systems and features for linking medical devices with patient data as disclosed in U.S. Patent No. 16/990,810, which is incorporated by reference in its entirety. Digital filing cabinets can be used to receive user feedback as described in U.S. Application No. 16/699,447, which is incorporated by reference in its entirety. The system disclosed herein can include digital filing cabinets for designing medical devices using the methods disclosed in U.S. Application No. 16/699,447.

[0044] The system 100 includes a client computing device 102, which can be a user device, such as a smartphone, mobile device, laptop, desktop, personal computer, tablet, phablet, wearable device (e.g., smartwatch), or other such devices known in the art. As discussed further herein, the client computing device 102 can include one or more

processors, and memory storing instructions executable by the one or more processors to perform the methods described herein. The client computing device 102 can be associated with a healthcare provider or a patient. Although FIG. 1 illustrates a single client computing device 102, in alternative embodiments, the client computing device 102 can instead be implemented as a client computing system encompassing a plurality of computing devices, such that the operations described herein with respect to the client computing device 102 can instead be performed by the computing system and/or the plurality of computing devices.

[0045] The client computing device 102 is configured to receive patient healthcare data 108 associated with a patient. The patient healthcare data 108 can include data representative of the patient's condition, anatomy, pathology, medical history, preferences, and/or any other information or parameters relevant to the patient. For example, the patient healthcare data 108 can include medical history, surgical intervention data, treatment outcome data, progress data (e.g., physician notes), patient feedback (e.g., feedback acquired using quality of life questionnaires, surveys), clinical data, provider information (e.g., physician, hospital, surgical team), patient information (e.g., demographics, sex, age, height, weight, type of pathology, occupation, activity level, tissue information, health rating, comorbidities, health related quality of life (HRQL)), vital signs, diagnostic results, medication information, allergies, image data (e.g., camera images, Magnetic Resonance Imaging (MRI) images, ultrasound images, Computerized Aided Tomography (CAT) scan images, Positron Emission Tomography (PET) images, X-Ray images), diagnostic equipment information (e.g., manufacturer, model number, specifications, user-selected settings/configurations, etc.), or the like. In some embodiments, the patient healthcare data 108 includes data representing one or more of patient identification number (ID), age, gender, body mass index (BMI), lumbar lordosis, Cobb angle(s), pelvic incidence, disc height, segment flexibility, bone quality, rotational displacement, and/or treatment level of the spine. In some embodiments, the client computing device 102 can locally store the digital filing cabinet 180, healthcare data 108, and/or other information. The client computing device 102 can store account information for allowing the user to automatically access remote digital filing cabinets or accounts with or without login credentials. In some embodiments, the client computing device 102 can periodically or continuously receive newly available data (e.g., biometrics from wearables, user input, etc.) and can transmit all of or a portion of the newly available

data to, for example, remote storage systems, such as the digital filing cabinet 180, server 106, or the like.

[0046] The client computing device 102 is operably connected via a communication network 104 to a server 106, thus allowing for data transfer between the client computing device 102 and the server 106. The communication network 104 may be a wired and/or a wireless network. The communication network 104, if wireless, may be implemented using communication techniques such as Visible Light Communication (VLC), Worldwide Interoperability for Microwave Access (WiMAX), Long term evolution (LTE), Wireless local area network (WLAN), Infrared (IR) communication, Public Switched Telephone Network (PSTN), Radio waves, and/or other communication techniques known in the art.

[0047] The server 106, which may also be referred to as a “healthcare data network” or “healthcare data analytics network,” can include one or more computing devices and/or systems. As discussed further herein, the server 106 can include one or more processors, and memory storing instructions executable by the one or more processors to perform the methods described herein. In some embodiments, the server 106 is implemented as a distributed “cloud” computing system or facility across any suitable combination of hardware and/or virtual computing resources.

[0048] The cloud analytics integration platform 126 is connected to the communication network 104. The analytics integration platform 126 can analyze the healthcare data and integrate data collected from the patient and healthcare providers into digital filing cabinet. The analytics integration platform 126 can integrate surgical plans and patient plan, identify health metrics of concern for the patient, display patient information and goals, perform post-operative analytics, and generation of healthcare provider or patient notifications (e.g., monitoring based on data from wearables, requesting updated information, scheduling appointment, or notifying of emergencies).

[0049] The medical implant 150 can be an intervertebral device that includes a body 152 configured to interface with one or more identified anatomical structures (e.g., one or more vertebral bodies or endplates) at and/or proximate the target implantation site (e.g., between one or more vertebral bodies or endplates). The implant body 152 can include one or more structural features designed to engage one or more identified anatomical structures. For example, in the illustrated embodiment, the implant 150 can include an upper surface 165 and a lower surface (not shown) configured to seat against

vertebral bodies of spine. In some embodiments, the upper surface 165 and the lower surface can have contours that match contours of the vertebral endplates, such that the upper surface 165 and lower surface “mate” with the corresponding vertebral endplates they engage with. The dimensions, contours, topology, composition, and/or other implant data can be part of the EMR. In some embodiments, such as the illustrated embodiment, the upper surface 165 and/or the lower surface can be textured (e.g., via roughenings, knurlings, ridges, and the like). Texturing data can be part of the manufacturing data stored in the EMRs. For lordotic correction, the upper surface 165 and the lower surface may be angled with respect to one another, and the EMR can include the angle and sizes of these surfaces.

[0050] A user (e.g., a physician, healthcare provider, patient, etc.) can access EMRs using a retrieval feature 160. For example, in embodiments in which the retrieval feature 160 is a bar code corresponding to the unique identifier, the user can scan the retrieval feature 160 using, for example, one or more cameras on the computing device and/or otherwise input the unique identifier into the computing device. Once the unique identifier is inputted into the computing system, the computing system can send the unique identifier to a remote server (e.g., via a communication network) with a request to provide the corresponding patient-specific healthcare data set. In response to the request, and as described above, the server can locate the specific data set associated with the unique identifier and transmit the data set to the computing device for display to the user. The implant 150 can include other features assisting with accessing the ledger and viewing the EMRs.

[0051] The retrieval feature 160 can be used to carry patient data, such as a private key for unlocking patient medical records stored on a blockchain ledger. The medical implant 150 can be blockchain-enabled to establish communicative contact using a proximity communication mode. A private key stored on the retrieval feature 160 can be used to access the patient-specific healthcare data. In some implementations, the medical implant 150 also contains a private blockchain ledger for tracking EMRs associated with the patient. As the patient undergoes various treatments, new EMRs and updates to existing EMRs for the patient are generated and stored as “transactions” in a blockchain ledger. To access the EMRs associated with the patient, the private key from the medical implant 150 must be used to “unlock” the EMRs stored in the blockchain ledger. The patient can provide this private key to healthcare providers and other

interested parties by a secure platform, mobile application, digital key, or the like. In some embodiments, the EMRs are encrypted using an encryption key that the healthcare provider decrypts. Additionally or alternatively, re-keying protocols, certification management protocols (e.g., enrollment certification protocol, transaction certification protocol, etc.), and other protocols and can be utilized for variable access and permissions. The patient can manage the data of the EMR to share selected data only. For example, the patient can keep a section of the EMR private while sharing another section of the EMR. The system also allows for user-controlled settings, such as settings for minors, family members, relatives, and/or other user-controlled settings.

[0052] An EMR can include patient data associated with the implant design and design process. If the implant is an artificial disc, for example, the stored data can include kinematic data (e.g., pre-operative patient data, target kinematic data, etc.), manufacturing data, design parameters, target service life data, physician recommendations/notes, etc. The disc can include an articulating implant body with plates contoured to match vertebral endplates, custom articulating members between the plates for providing patient-specific motion, etc. If the implant is an intervertebral cage, the stored data can include materials specifications of the implant body, dimensions of the implant body, manufacturing data, design parameters, target service life data, physician recommendations/notes, etc. The applications and patents incorporated by reference disclose data (e.g., surgical plans, implant specifications, data sets, etc.) that can be associated with the retrieval feature 160.

[0053] In some implementations, the patient can set variable permissions for access to transactions and details stored in the blockchain ledger. For example, particular medical providers may only be given access to certain transactions related to particular kinds of medical procedures. In other implementations, permissions can be set based on the patient, such as having child settings for children with an implant.

[0054] The medical implant 150 can also track and monitor various health related data for the patient. For example, the medical implant 150 can include one or more sensors configured to measure pressures, loads, or forces applied by anatomical elements to monitor, for example, activity, loading, etc. The medical implant 150 can continuously or periodically collect data indicating activity level, activities performed, disease progression, or the like. For example, loading across the implant 150 can be

tracked over period of time. The applications and patents incorporated by reference disclose techniques for monitoring, collecting data, and transmitting data. In some embodiments, the medical implant 150 can identify events, such as excess loading, imbalance of the spine, or the like. In some embodiments, the patient is monitored with automatic blockchain updating based on activity (e.g., surgical procedure, change in status, etc.), disability (e.g., new disability, progression of disability, etc.), and/or healthcare events. The healthcare events can include imaging, diagnosis, treatment, and/or outcomes and event data that can be encoded in the blockchain. Collected data can be used as historical patient data used to treat another patient. The applications and patents incorporated by reference also disclose usage of historical data, imaging data, surgical plans, simulations, modeled outcomes, treatment protocols, and outcome values that can be encoded in the blockchain. The digital filing cabinets can also track and monitor various health related data for the patient and can include one or more blockchain digital wallets for managing blockchain data. The number, configuration, and/or contents of digital wallets can be selected by the user, physician, etc. The digital wallet can be used to access blockchains to automatically update blockchains for any number of implants.

[0055] In some implementations, two or more implants can be used. For example, a patient can have both a spinal implant with an encoded chip containing the private key and/or the private blockchain ledger containing the EMRs of the patient and a subcutaneous digital implant. The subcutaneous digital implant acts as an intermediary device, communicating with both the spinal implant containing the private key and/or the private blockchain ledger and an external computing device, such as a patient treatment computing system. The subcutaneous digital implant may also include data of its own, such as patient identifying information, biometric data, and the like. In some embodiments, the subcutaneous digital implant may include the private key and/or the private blockchain ledger containing the EMRs of the patient.

[0056] The patient-specific implant can be any of the implants described herein or in any patent references incorporated by reference herein. For example, the patient-specific implant can include one or more of screws (e.g., bone screws, spinal screws, pedicle screws, facet screws), interbody implant devices (e.g., intervertebral implants), cages, plates, rods, discs, fusion devices, spacers, rods, expandable devices, stents,

brackets, ties, scaffolds, fixation device, anchors, nuts, bolts, rivets, connectors, tethers, fasteners, joint replacements (e.g., artificial discs), hip implants, or the like.

[0057] A patient-specific implant design can include data representing one or more of physical properties (e.g., size, shape, volume, material, mass, weight), mechanical properties (e.g., stiffness, strength, modulus, hardness), and/or biological properties (e.g., osteo-integration, cellular adhesion, anti-bacterial properties, anti-viral properties) of the implant. For example, a design for an orthopedic implant can include implant shape, size, material, and/or effective stiffness (e.g., lattice density, number of struts, location of struts, etc.).

[0058] Additional implant types, configurations, and structural features suitable for engaging identified anatomical features are described, for example, in U.S. Application No. 16/207,116, filed December 1, 2018, and U.S. Application No. 16/987,113, filed August 6, 2020, the disclosures of which are incorporated by reference herein in their entireties. For example, the medical implants can be pedicle screws, patient-specific implants, interbody implant systems, artificial discs, expandable intervertebral implants, sacroiliac implants, plates, arthroplasty devices for orthopedic joints, non-structural implants, or other devices disclosed in the patents and applications incorporated herein by reference.

[0059] The medical implant 150 can be used to track and monitor medical data associated with the patient. U.S. Application No. 63/218,190 discloses implants capable of collecting data, assigning weighting/values, and communicating with other devices. The monitoring can be used with prescriptive systems, such as the systems disclosed in U.S. Patent No. 10,902,944 and U.S. Application No. 17/342,439, which are incorporated by reference in their entireties. For example, the patient's data can be incorporated into one or more training sets for a machine learning system or other systems disclosed in the incorporated by reference patents and applications. The medical implant 150 can also be a multipurpose implant, providing structure to address a medical issue in the body of the patient while also carrying information regarding the patient. For example, the medical implant 150 can be a pacemaker, a plate or pin to correctly position a previously broken bone or set of bones, and the like. The digital filing cabinet 180 can also be incorporated into the systems disclosed in U.S. Patent No. 10,902,944 and U.S. Application No. 17/342,439 to track and monitor patient-managed medical data.

[0060] The computing system 100 can transmit surgical plan(s)/plan report(s) (e.g., surgical plan 1000 of Figure 10A, surgical plan report 1100 of Figure 11, etc.), implant designs, and other data via the communication network 104 to the client computing device 102 for output to a user (e.g., clinician, surgeon, healthcare provider, patient). In some embodiments, the client computing device 102 includes or is operably coupled to an electronic display for outputting the treatment plan(s). The display can include a graphical user interface (GUI) for visually depicting various aspects of the surgical plan(s). For example, the display can show various aspects of a surgical procedure to be performed on the patient, such as the surgical approach, treatment levels, corrective maneuvers, tissue resection, and/or implant placement. To facilitate visualization, the surgical plan can include a virtual model of the surgical procedure that can be displayed via the display. The display may also display additional aspects of the surgical plan, such as predicted post-operative patient metrics, predicted disease progression metrics associated with the identified surgical procedure, etc. As another example, the device 102 can show a design for a medical device to be implanted in the patient in accordance with the transmitted surgical plan, such as a two- or three-dimensional model of the device design. The device 102 can also show patient information, such as two- or three-dimensional images or models of the patient's anatomy where the surgical procedure is to be performed and/or where the device is to be implanted. The client computing device 102 can further include one or more user input devices (not shown) allowing the user to modify, select, approve, and/or reject the displayed treatment plan(s).

[0061] In some embodiments, one or more aspects of the surgical plan are displayed using a surgical plan review program. The review program, which may be implemented as a mobile phone application, a computer application, or the like, can display (e.g., via the computing device 102) one or more aspects of the surgical plan (e.g., a surgical procedure, a virtual model of patient anatomy, an implant, etc.). The review program may provide an interactive interface that further enables a surgeon to select between different patients, select between different surgical plans for the same patient, compare surgical plans for the same patient, review the status of a surgical plan, provide feedback on a proposed surgical plan, accept a surgical plan, reject a surgical plan, etc. The review program may further enable a surgeon or other user to select between different views of a virtual model of patient anatomy, and/or different views of a patient-specific implant to be used in the surgical plan.

[0062] In some embodiments, medical device design(s) generated by the treatment planning module 118 can be transmitted from the client computing device 102 and/or server 106 to a manufacturing system 124 for manufacturing corresponding medical device(s). The manufacturing system 124 can be located on site or off site. On-site manufacturing can reduce the number of sessions with a patient and/or the time to be able to perform the surgery whereas off-site manufacturing can be useful in making the complex devices. Off-site manufacturing facilities can have specialized manufacturing equipment. In some embodiments, more complicated device components can be manufactured off site, while simpler device components can be manufactured on site.

[0063] The client computing device 102 and server 106 can individually or collectively perform the various methods described herein for storing and retrieving healthcare data. For example, some or all of the steps of the methods described herein can be performed by the client computing device 102 alone, the server 106 alone, or a combination of the client computing device 102 and the server 106. In some embodiments, the client computing device 102 includes one or more digital filing cabinets 180. Thus, although certain operations are described herein with respect to the server 106, it shall be appreciated that these operations can also be performed by the client computing device 102, and vice-versa.

[0064] The server 106 includes at least one database 110 configured to store reference data useful for the providing, managing, or analyzing patient-specific healthcare data from an implant methods described herein. The reference data can include historical and/or clinical data from the same or other patients, data collected from prior surgeries and/or other treatments of patients by the same or other healthcare providers, data relating to medical device designs, data collected from study groups or research groups, data from practice databases, data from academic institutions, data from implant manufacturers or other medical device manufacturers, data from imaging studies, data from simulations, clinical trials, demographic data, treatment data, outcome data, mortality rates, or the like.

[0065] In some embodiments, the database 110 includes a plurality of reference patient data sets, each patient reference data set associated with a corresponding reference patient. For example, the reference patient can be a patient that previously received treatment or is currently receiving treatment. Each reference patient data set

can include data representative of the corresponding reference patient's condition, anatomy, pathology, medical history, disease progression, preferences, and/or any other information or parameters relevant to the reference patient, such as any of the data described herein with respect to the healthcare data 108. In some embodiments, the reference patient data set includes pre-operative data, intra-operative data, and/or post-operative data. For example, a reference patient data set can include data representing one or more of patient ID, age, gender, BMI, lumbar lordosis, Cobb angle(s), pelvic incidence, disc height, segment flexibility, bone quality, rotational displacement, and/or treatment level of the spine. As another example, a reference patient data set can include treatment data regarding at least one treatment procedure performed on the reference patient, such as descriptions of surgical procedures or interventions (e.g., surgical approaches, bony resections, surgical maneuvers, corrective maneuvers, placement of implants or other devices). In some embodiments, the treatment data includes medical device design data for at least one medical device used to treat the reference patient, such as physical properties (e.g., size, shape, volume, material, mass, weight), mechanical properties (e.g., stiffness, strength, modulus, hardness), and/or biological properties (e.g., osteo-integration, cellular adhesion, anti-bacterial properties, anti-viral properties). In yet another example, a reference patient data set can include outcome data representing an outcome of the treatment of the reference patient, such as corrected anatomical metrics, presence of fusion, HRQL, activity level, return to work, complications, recovery times, efficacy, mortality, and/or follow-up surgeries.

[0066] In some embodiments, the server 106 receives at least some of the reference patient data sets from a plurality of healthcare provider computing systems (e.g., systems 112a-112c, collectively 112), digital filing cabinets, or combinations thereof. The server 106 can be connected to the healthcare provider computing systems 112 via one or more communication networks (not shown). Each healthcare provider computing system 112 can be associated with a corresponding healthcare provider (e.g., physician, surgeon, medical clinic, hospital, healthcare network, etc.). Each healthcare provider computing system 112 can include at least one reference patient data set (e.g., reference patient data sets 114a-114c, collectively 114) associated with reference patients treated by the corresponding healthcare provider. The reference patient data sets 114 can include, for example, electronic medical records, electronic health records, biomedical data sets, etc. The reference patient data sets 114 can be received by the

server 106 from the healthcare provider computing systems 112 and can be reformatted into different formats for storage in the database 110. Optionally, the reference patient data sets 114 can be processed (e.g., cleaned) to ensure that the represented patient parameters are likely to be useful in the treatment planning methods described herein.

[0067] As described in further detail herein, the server 106 can be configured with one or more algorithms that generate patient-specific treatment plan data (e.g., treatment procedures, medical devices) based on the reference data. In some embodiments, the patient-specific data is generated based on correlations between the patient data set 108 and the reference data. Optionally, the server 106 can predict outcomes, including recovery times, efficacy based on clinical end points, likelihood of success, predicted mortality, predicted related follow-up surgeries, or the like. In some embodiments, the server 106 can continuously or periodically analyze patient data (including patient data obtained during the patient stay) to determine near real-time or real-time risk scores, mortality prediction, etc.

[0068] In some embodiments, the server 106 includes one or more modules for performing one or more steps of the patient-specific treatment planning methods described herein. For example, in the depicted embodiment, the server 106 includes a data analysis module 116 and a treatment planning module 118. In alternative embodiments, one or more of these modules may be combined with each other, or may be omitted. Thus, although certain operations are described herein with respect to a particular module or modules, this is not intended to be limiting, and such operations can be performed by a different module or modules in alternative embodiments.

[0069] The data analysis module 116 is configured with one or more algorithms for identifying a subset of reference data from the database 110 that is likely to be useful in developing a patient-specific treatment plan. The database 110 can retrieve or receive data from the client computing device 102, digital filing cabinet 180, or other data source. For example, the data analysis module 116 can compare patient-specific data (e.g., the patient data set 108 received from the client computing device 102) to the reference data from the database 110 (e.g., the reference patient data sets) to identify similar data (e.g., one or more similar patient data sets in the reference patient data sets). The reference data can be updated in real-time or almost real-time using other patient data accessible via the network 104. The comparison can be based on one or more parameters, such

as age, gender, BMI, lumbar lordosis, pelvic incidence, and/or treatment levels. The parameter(s) can be used to calculate a similarity score for each reference patient. The similarity score can represent a statistical correlation between the patient data set 108 and the reference patient data set. Accordingly, similar patients can be identified based on whether the similarity score is above, below, or at a specified threshold value. For example, as described in greater detail below, the comparison can be performed by assigning values to each parameter and determining the aggregate difference between the subject patient and each reference patient. Reference patients whose aggregate difference is below a threshold can be considered to be similar patients.

[0070] The data analysis module 116 can further be configured with one or more algorithms to select a subset of the reference patient data sets, e.g., based on similarity to the patient data set 108 and/or treatment outcome of the corresponding reference patient. For example, the data analysis module 116 can identify one or more similar patient data sets in the reference patient data sets, and then select a subset of the similar patient data sets based on whether the similar patient data set includes data indicative of a favorable or desired treatment outcome. The outcome data can include data representing one or more outcome parameters, such as corrected anatomical metrics, presence of fusion, HRQL, activity level, complications, recovery times, efficacy, mortality, or follow-up surgeries. As described in further detail below, in some embodiments, the data analysis module 116 calculates an outcome score by assigning values to each outcome parameter. A patient can be considered to have a favorable outcome if the outcome score is above, below, or at a specified threshold value.

[0071] In some embodiments, the data analysis module 116 selects a subset of the reference patient data sets based at least in part on user input (e.g., from a clinician, surgeon, physician, healthcare provider). For example, the user input can be used in identifying similar patient data sets. In some embodiments, weighting of similarity and/or outcome parameters can be selected by a healthcare provider or physician to adjust the similarity and/or outcome score based on clinician input. In further embodiments, the healthcare provider or physician can select the set of similarity and/or outcome parameters (or define new similarity and/or outcome parameters) used to generate the similarity and/or outcome score, respectively.

[0072] In some embodiments, the data analysis module 116 includes one or more algorithms used to select a set or subset of the reference patient data sets based on criteria other than patient parameters. For example, the one or more algorithms can be used to select the subset based on healthcare provider parameters (e.g., based on healthcare provider ranking/scores such as hospital/physician expertise, number of procedures performed, hospital ranking, etc.) and/or healthcare resource parameters (e.g., diagnostic equipment, facilities, surgical equipment such as surgical robots), or other non-patient related information that can be used to predict outcomes and risk profiles for procedures for the present healthcare provider. For example, reference patient data sets with images captured from similar diagnostic equipment can be aggregated to reduce or limit irregularities due to variation between diagnostic equipment. Additionally, patient-specific treatment plans can be developed for a particular health-care provider using data from similar healthcare providers (e.g., healthcare providers with traditionally similar outcomes, physician expertise, surgical teams, etc.). In some embodiments, reference healthcare provider data sets, hospital data sets, physician data sets, surgical team data sets, post-treatment data set, and other data sets can be utilized. By way of example, a patient-specific treatment plan to perform a battlefield surgery can be based on reference patient data from similar battlefield surgeries and/or datasets associated with battlefield surgeries. In another example, the patient-specific treatment plan can be generated based on available robotic surgical systems. The reference patient data sets can be selected based on patients that have been operated on using comparable robotic surgical systems under similar conditions (e.g., size and capabilities of surgical teams, hospital resources, etc.).

[0073] The treatment planning module 118 is configured with one or more algorithms to generate at least one treatment plan or recovery protocol (e.g., pre-operative plans, surgical plans, post-operative plans etc.) based on the output from the data analysis module 116. In some embodiments, the treatment planning module 118 is configured to develop and/or implement at least one predictive model for generating the patient-specific treatment plan, also known as a “prescriptive model.” The predictive model(s) can be developed using clinical knowledge, statistics, machine learning, AI, neural networks, or the like. In some embodiments, the output from the data analysis module 116 is analyzed (e.g., using statistics, machine learning, neural networks, AI) to identify correlations between data sets, patient parameters, healthcare provider

parameters, healthcare resource parameters, treatment procedures, medical device designs, and/or treatment outcomes. These correlations can be used to develop at least one predictive model that predicts the likelihood that a treatment plan will produce a favorable outcome for the particular patient. The predictive model(s) can be validated, e.g., by inputting data into the model(s) and comparing the output of the model to the expected output and actual output following treatment.

[0074] In some embodiments, the treatment planning module 118 is configured to generate the treatment plan based on previous treatment data from reference patients. For example, the treatment planning module 118 can receive a selected subset of reference patient data sets and/or similar patient data sets from the data analysis module 116, and determine or identify treatment data from the selected subset. The treatment data can include, for example, treatment procedure data (e.g., surgical procedure or intervention data) and/or medical device design data (e.g., implant design data) that are associated with favorable or desired treatment outcomes for the corresponding patient. The treatment planning module 118 can analyze the treatment procedure data and/or medical device design data to determine an optimal treatment protocol for the patient to be treated. For example, the treatment procedures and/or medical device designs can be assigned values and aggregated to produce a treatment score. The patient-specific treatment plan can be determined by selecting treatment plan(s) based on the score (e.g., higher or highest score; lower or lowest score; score that is above, below, or at a specified threshold value). The personalized patient-specific treatment plan can be based on, at least in part, the patient-specific technologies or patient-specific selected technology.

[0075] Alternatively or in combination, the treatment planning module 118 can generate the treatment plan based on correlations between data sets. For example, the treatment planning module 118 can correlate treatment procedure data and/or medical device design data from similar patients with favorable outcomes (e.g., as identified by the data analysis module 116). Correlation analysis can include transforming correlation coefficient values to values or scores. The values/scores can be aggregated, filtered, or otherwise analyzed to determine one or more statistical significances. These correlations can be used to determine treatment procedure(s) and/or medical device design(s) that are optimal or likely to produce a favorable outcome for the patient to be treated.

[0076] Alternatively or in combination, the treatment planning module 118 can generate the treatment plan using one or more AI techniques. AI techniques can be used to develop computing systems capable of simulating aspects of human intelligence, e.g., learning, reasoning, planning, problem solving, decision making, etc. AI techniques can include, but are not limited to, case-based reasoning, rule-based systems, artificial neural networks, decision trees, support vector machines, regression analysis, Bayesian networks (e.g., naïve Bayes classifiers), genetic algorithms, cellular automata, fuzzy logic systems, multi-agent systems, swarm intelligence, data mining, machine learning (e.g., supervised learning, unsupervised learning, reinforcement learning), and hybrid systems.

[0077] In some embodiments, the treatment planning module 118 generates the treatment plan using one or more trained machine learning models. Various types of machine learning models, algorithms, and techniques are suitable for use with the present technology. In some embodiments, the machine learning model is initially trained on a training data set, which is a set of examples used to fit the parameters (e.g., weights of connections between “neurons” in artificial neural networks) of the model. For example, the training data set can include any of the reference data stored in database 110, such as a plurality of reference patient data sets or a selected subset thereof (e.g., a plurality of similar patient data sets).

[0078] In some embodiments, the machine learning model (e.g., a neural network or a naïve Bayes classifier) may be trained on the training data set using a supervised learning method (e.g., gradient descent or stochastic gradient descent). The training dataset can include pairs of generated “input vectors” with the associated corresponding “answer vector” (commonly denoted as the target). The current model is run with the training data set and produces a result, which is then compared with the target, for each input vector in the training data set. Based on the result of the comparison and the specific learning algorithm being used, the parameters of the model are adjusted. The model fitting can include both variable selection and parameter estimation. The fitted model can be used to predict the responses for the observations in a second data set called the validation data set. The validation data set can provide an unbiased evaluation of a model fit on the training data set while tuning the model parameters. Validation data sets can be used for regularization by early stopping, e.g., by stopping training when the error on the validation data set increases, as this may be a sign of overfitting to the training data set. In some embodiments, the error of the validation data set error can

fluctuate during training, such that ad-hoc rules may be used to decide when overfitting has truly begun. Finally, a test data set can be used to provide an unbiased evaluation of a final model fit on the training data set.

[0079] To generate a treatment plan, the patient data set 108 can be input into the trained machine learning model(s). Additional data, such as the selected subset of reference patient data sets and/or similar patient data sets, and/or treatment data from the selected subset, can also be input into the trained machine learning model(s). The trained machine learning model(s) can then calculate whether various candidate treatment procedures and/or medical device designs are likely to produce a favorable outcome for the patient. Based on these calculations, the trained machine learning model(s) can select at least one treatment plan for the patient. In embodiments where multiple trained machine learning models are used, the models can be run sequentially or concurrently to compare outcomes and can be periodically updated using training data sets. The treatment planning module 118 can use one or more of the machine learning models based the model's predicted accuracy score.

[0080] The patient-specific treatment plan generated by the treatment planning module 118 can include at least one patient-specific treatment procedure (e.g., a surgical procedure or intervention) and/or at least one patient-specific medical device (e.g., an implant or implant delivery instrument). A patient-specific treatment plan can include an entire surgical procedure or portions thereof. Additionally, one or more patient-specific medical devices can be specifically selected or designed for the corresponding surgical procedure, thus allowing for the various components of the patient-specific technology to be used in combination to treat the patient.

[0081] In some embodiments, the patient-specific treatment procedure includes an orthopedic surgery procedure, such as spinal surgery, hip surgery, knee surgery, jaw surgery, hand surgery, shoulder surgery, elbow surgery, total joint reconstruction (arthroplasty), skull reconstruction, foot surgery, or ankle surgery. Spinal surgery can include spinal fusion surgery, such as posterior lumbar interbody fusion (PLIF), anterior lumbar interbody fusion (ALIF), transverse or transforaminal lumbar interbody fusion (TLIF), lateral lumbar interbody fusion (LLIF), direct lateral lumbar interbody fusion (DLIF), or extreme lateral lumbar interbody fusion (XLIF). In some embodiments, the patient-specific treatment procedure includes descriptions of and/or instructions for

performing one or more aspects of a patient-specific surgical procedure. For example, the patient-specific surgical procedure can include one or more of a surgical approach, a corrective maneuver, a bony resection, or implant placement.

[0082] In some embodiments, the patient-specific medical device design includes a design for an orthopedic implant and/or a design for an instrument for delivering an orthopedic implant. Examples of such implants include, but are not limited to, screws (e.g., bone screws, spinal screws, pedicle screws, facet screws), interbody implant devices (e.g., intervertebral implants), cages, plates, rods, disks, fusion devices, spacers, rods, expandable devices, stents, brackets, ties, scaffolds, fixation device, anchors, nuts, bolts, rivets, connectors, tethers, fasteners, joint replacements, hip implants, or the like. Examples of instruments include, but are not limited to, screw guides, cannulas, ports, catheters, insertion tools, or the like.

[0083] A patient-specific medical device design can include data representing one or more of physical properties (e.g., size, shape, volume, material, mass, weight), mechanical properties (e.g., stiffness, strength, modulus, hardness), and/or biological properties (e.g., osteo-integration, cellular adhesion, anti-bacterial properties, anti-viral properties) of a corresponding medical device. For example, a design for an orthopedic implant can include implant shape, size, material, and/or effective stiffness (e.g., lattice density, number of struts, location of struts, etc.). In some embodiments, the generated patient-specific medical device design is a design for an entire device. Alternatively, the generated design can be for one or more components of a device, rather than the entire device.

[0084] In some embodiments, the design is for one or more patient-specific device components that can be used with standard, off-the-shelf components. For example, in a spinal surgery, a pedicle screw kit can include both standard components and patient-specific customized components. In some embodiments, the generated design is for a patient-specific medical device that can be used with a standard, off-the-shelf delivery instrument. For example, the implants (e.g., screws, screw holders, rods) can be designed and manufactured for the patient, while the instruments for delivering the implants can be standard instruments. This approach allows the components that are implanted to be designed and manufactured based on the patient's anatomy and/or surgeon's preferences to enhance treatment. The patient-specific devices described

herein are expected to improve delivery into the patient's body, placement at the treatment site, and/or interaction with the patient's anatomy.

[0085] In embodiments where the patient-specific treatment plan includes a surgical procedure to implant a medical device, the treatment planning module 118 can also store various types of implant surgery information, such as implant parameters (e.g., types, dimensions), availability of implants, aspects of a pre-operative plan (e.g., initial implant configuration, detection and measurement of the patient's anatomy, etc.), FDA requirements for implants (e.g., specific implant parameters and/or characteristics for compliance with FDA regulations), or the like. In some embodiments, the treatment planning module 118 can convert the implant surgery information into formats useable for machine-learning based models and algorithms. For example, the implant surgery information can be tagged with particular identifiers for formulas or can be converted into numerical representations suitable for supplying to the trained machine learning model(s). The treatment planning module 118 can also store information regarding the patient's anatomy, such as two- or three-dimensional images or models of the anatomy, and/or information regarding the biology, geometry, and/or mechanical properties of the anatomy. The anatomy information can be used to inform implant design and/or placement.

[0086] The treatment plan(s) generated by the treatment planning module 118 can be transmitted via the communication network 104 to the digital filing cabinet 180 and/or client computing device 102 for output to a user (e.g., clinician, surgeon, healthcare provider, patient). In some embodiments, the client computing device 102 includes or is operably coupled to a display for outputting the treatment plan(s). The display can include a graphical user interface (GUI) for visually depicting various aspects of the treatment plan(s). For example, the display can show various aspects of a surgical procedure to be performed on the patient, such as the surgical approach, treatment levels, corrective maneuvers, tissue resection, and/or implant placement. To facilitate visualization, a virtual model of the surgical procedure can be displayed. As another example, the display can show a design for a medical device to be implanted in the patient, such as a two- or three-dimensional model of the device design. The display can also show patient information, such as two- or three-dimensional images or models of the patient's anatomy where the surgical procedure is to be performed and/or where the device is to be implanted. The client computing device 102 can further include one or

more user input devices (not shown) allowing the user to modify, select, approve, and/or reject the displayed treatment plan(s).

[0087] In some embodiments, the medical device design(s) generated by the treatment planning module 118 can be transmitted from the client computing device 102 and/or server 106 to a manufacturing system 124 for manufacturing an implant or a corresponding medical device. The manufacturing system 124 can be located on site or off site. The implant may be manufactured by any suitable manufacturing system (e.g., the manufacturing system 124 shown in FIG. 1). The digital filing cabinet 180 can store the generated medical device design(s), manufacturing data (e.g., CAM data, print data, etc.), manufacturing information, data for generating surgical plans, surgical plans, surgical plan reports, post-operative data (e.g., therapy plans, predicted outcomes, etc.), and/or other information associated with the medical device.

[0088] Various types of manufacturing systems are suitable for use in accordance with the embodiments herein. For example, the manufacturing system 124 can be configured for additive manufacturing, such as three-dimensional (3D) printing, stereolithography (SLA), digital light processing (DLP), fused deposition modeling (FDM), selective laser sintering (SLS), selective laser melting (SLM), selective heat sintering (SHM), electronic beam melting (EBM), laminated object manufacturing (LOM), powder bed printing (PP), thermoplastic printing, direct material deposition (DMD), inkjet photo resin printing, or like technologies, or combination thereof. Alternatively or in combination, the manufacturing system 124 can be configured for subtractive (traditional) manufacturing, such as CNC machining, electrical discharge machining (EDM), grinding, laser cutting, water jet machining, manual machining (e.g., milling, lathe/turning), or like technologies, or combinations thereof. The manufacturing system 124 can manufacture one or more patient-specific medical devices based on fabrication instructions or data (e.g., CAD data, 3D data, digital blueprints, stereolithography data, or other data suitable for the various manufacturing technologies described herein). Different components of the system 100 can generate at least a portion of the manufacturing data used by the manufacturing system 124. The manufacturing data can include, without limitation, fabrication instructions (e.g., programs executable by additive manufacturing equipment, subtractive manufacturing equipment, etc.), 3D data, CAD data (e.g., CAD files), CAM data (e.g., CAM files), path data (e.g., print head paths, tool paths, etc.), material data, tolerance data, surface finish data (e.g., surface roughness data), regulatory data (e.g.,

FDA requirements, reimbursement data, etc.), or the like. The manufacturing system 124 can analyze the manufacturability of the implant design based on the received manufacturing data. The implant design can be finalized by altering geometries, surfaces, etc. and then generating manufacturing instructions. In some embodiments, the server 106 generates at least a portion of the manufacturing data, which is transmitted to the manufacturing system 124.

[0089] The manufacturing system 124 can generate CAM data, print data (e.g., powder bed print data, thermoplastic print data, photo resin data, etc.), or the like and can include additive manufacturing equipment, subtractive manufacturing equipment, thermal processing equipment, or the like. The additive manufacturing equipment can be 3D printers, stereolithography devices, digital light processing devices, fused deposition modeling devices, selective laser sintering devices, selective laser melting devices, electronic beam melting devices, laminated object manufacturing devices, powder bed printers, thermoplastic printers, direct material deposition devices, or inkjet photo resin printers, or like technologies. The subtractive manufacturing equipment can be CNC machines, electrical discharge machines, grinders, laser cutters, water jet machines, manual machines (e.g., milling machines, lathes, etc.), or like technologies. Both additive and subtractive techniques can be used to produce implants with complex geometries, surface finishes, material properties, etc. The generated fabrication instructions can be configured to cause the manufacturing system 124 to manufacture the patient-specific orthopedic implant that matches or is therapeutically the same as the patient-specific design. In some embodiments, the patient-specific medical device can include features, materials, and designs shared across designs to simplify manufacturing. For example, deployable patient-specific medical devices for different patients can have similar internal deployment mechanisms but have different deployed configurations. In some embodiments, the components of the patient-specific medical devices are selected from a set of available pre-fabricated components and the selected pre-fabricated components can be modified based on the fabrication instructions or data.

[0090] Following the treatment of the patient in accordance with the treatment plan, treatment progress can be monitored over one or more time periods to update the data analysis module 116 and/or treatment planning module 118. Post-treatment data can be added to the reference data stored in the database 110 and used for post-operative analytics. The post-treatment data can be used to train machine learning models for

developing patient-specific treatment plans, patient-specific medical devices, or combinations thereof.

[0091] It shall be appreciated that the components of the system 100 can be configured in many different ways. For example, in alternative embodiments, the database 110, the data analysis module 116 and/or the treatment planning module 118 can be components of the client computing device 102, rather than the server 106. As another example, the database 110, the data analysis module 116, and/or the treatment planning module 118 can be located across a plurality of different servers, computing systems, or other types of cloud-computing resources, rather than at a single server 106 or client computing device 102.

[0092] Additionally, in some embodiments, the system 100 can be operational with numerous other computing system environments or configurations. Examples of computing systems, environments, and/or configurations that may be suitable for use with the technology include, but are not limited to, personal computers, server computers, handheld or laptop devices, cellular telephones, wearable electronics, tablet devices, multiprocessor systems, microprocessor-based systems, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that include any of the above systems or devices, or the like.

[0093] FIG. 2 illustrates a computing device 200 suitable for use in connection with the system 100 of FIG. 1, according to an embodiment. The computing device 200 can be incorporated in various components of the system 100 of FIG. 1, such as the client computing device 102 or the server 106. The computing device 200 includes one or more processors 210 (e.g., CPU(s), GPU(s), HPU(s), etc.). The processor(s) 210 can be a single processing unit or multiple processing units in a device or distributed across multiple devices. The processor(s) 210 can be coupled to other hardware devices, for example, with the use of a bus, such as a PCI bus or SCSI bus. The processor(s) 210 can be configured to execute one or more computer-readable program instructions, such as program instructions to carry out any of the methods described herein.

[0094] The computing device 200 can include one or more input devices 220 that provide input to the processor(s) 210, e.g., to notify it of actions from a user of the device 200. The actions can be mediated by a hardware controller that interprets the signals received from the input device and communicates the information to the processor(s) 210.

using a communication protocol. Input device(s) 220 can include, for example, a mouse, a keyboard, a touchscreen, an infrared sensor, a touchpad, a wearable input device, a camera- or image-based input device, a microphone, or other user input devices.

[0095] The computing device 200 can include a display 230 used to display various types of output, such as text, models, virtual procedures, surgical plans, implants, graphics, and/or images (e.g., images with voxels indicating radiodensity units or Hounsfield units representing the density of the tissue at a location). In some embodiments, the display 230 provides graphical and textual visual feedback to a user. The processor(s) 210 can communicate with the display 230 via a hardware controller for devices. In some embodiments, the display 230 includes the input device(s) 220 as part of the display 230, such as when the input device(s) 220 include a touchscreen or is equipped with an eye direction monitoring system. In alternative embodiments, the display 230 is separate from the input device(s) 220. Examples of display devices include an LCD display screen, an LED display screen, a projected, holographic, or augmented reality display (e.g., a heads-up display device or a head-mounted device), and so on.

[0096] Optionally, other I/O devices 240 can also be coupled to the processor(s) 210, such as a network card, video card, audio card, USB, firewire or other external device, camera, printer, speakers, CD-ROM drive, DVD drive, disk drive, or Blu-Ray device. Other I/O devices 240 can also include input ports for information from directly connected medical equipment such as imaging apparatuses, including MRI machines, X-Ray machines, CT machines, etc. Other I/O devices 240 can further include input ports for receiving data from these types of machine from other sources, such as across a network or from previously captured data, for example, stored in a database.

[0097] In some embodiments, the computing device 200 also includes a communication device (not shown) capable of communicating wirelessly or wire-based with a network node. The communication device can communicate with another device or a server through a network using, for example, TCP/IP protocols. The computing device 200 can utilize the communication device to distribute operations across multiple network devices, including imaging equipment, manufacturing equipment, etc.

[0098] The computing device 200 can include memory 250, which can be in a single device or distributed across multiple devices. Memory 250 includes one or more of various hardware devices for volatile and non-volatile storage, and can include both read-

only and writable memory. For example, a memory can comprise random access memory (RAM), various caches, CPU registers, read-only memory (ROM), and writable non-volatile memory, such as flash memory, hard drives, floppy disks, CDs, DVDs, magnetic storage devices, tape drives, device buffers, and so forth. A memory is not a propagating signal divorced from underlying hardware; a memory is thus non-transitory. In some embodiments, the memory 250 is a non-transitory computer-readable storage medium that stores, for example, programs, software, data, or the like. In some embodiments, memory 250 can include program memory 260 that stores programs and software, such as an operating system 262, one or more healthcare data modules 264, and other application programs 266. The healthcare data module(s) 264 can include one or more modules configured to perform the various methods described herein (e.g., the data analysis module 116 and/or treatment planning module 118 described with respect to FIG. 1). Memory 250 can also include data memory 270 that can include, e.g., reference data, configuration data, settings, user options or preferences, etc., which can be provided to the program memory 260 or any other element of the computing device 200.

[0099] FIG. 3 is a system diagram illustrating an example of a computing environment in which the disclosed system operates in some embodiments. In some embodiments, environment 300 includes one or more client computing devices 305A-D, examples of which can host the device 200. Client computing devices 305 operate in a networked environment using logical connections through network 330 to one or more remote computers, such as a server computing device. In some implementations, the client computing devices 305 can also include a medical implant, such as the medical implant 150 described above in relation to FIG. 1.

[0100] In some embodiments, device 310 is an edge server which receives client requests and coordinates fulfillment of those requests through other servers, such as servers 320A-C. In some embodiments, server computing devices 310 and 320 comprise computing systems, such as the device 200. Though each server computing device 310 and 320 is displayed logically as a single server, server computing devices can each be a distributed computing environment encompassing multiple computing devices located at the same or at geographically disparate physical locations. In some embodiments, each server computing device 320 corresponds to a group of servers.

[0101] Client computing devices 305 and server computing devices 310 and 320 can each act as a server or client to other server or client devices. In some embodiments, servers (310, 320A-C) connect to a corresponding database (315, 325A-C). As discussed above, each server 320 can correspond to a group of servers, and each of these servers can share a database or can have its own database. Databases 315 and 325 warehouse (e.g., store) information such as medical information, health records, biometric information of users, blockchain transactions involving user medical records, and other data. In some embodiments, the servers 320A-C can include digital filing cabinets and/or features of other servers disclosed herein, such as server 106 of FIG. 1. Though databases 315 and 325 are displayed logically as single units, databases 315 and 325 can each be a distributed computing environment encompassing multiple computing devices, can be located within their corresponding server, or can be located at the same or at geographically disparate physical locations.

[0102] Network 330 can be a local area network (LAN) or a wide area network (WAN), but can also be other wired or wireless networks. In some embodiments, network 330 is the Internet or some other public or private network. Client computing devices 305 are connected to network 330 through a network interface, such as by wired or wireless communication. While the connections between server 310 and servers 320 are shown as separate connections, these connections can be any kind of local, wide area, wired, or wireless network, including network 330 or a separate public or private network.

[0103] FIG. 4 is a block diagram illustrating components 400 which, in some implementations, can be used in a system employing the disclosed technology. The components 400 can be used for storing, managing, analyzing, and accessing healthcare data in digital filing cabinets. The components 400 include hardware 402, general software 420, and specialized components 440. As discussed above, a system implementing the disclosed technology can use various hardware including processing units 404 (e.g., CPUs, GPUs, APUs, etc.), working memory 406, storage memory 408 (local storage or as an interface to remote storage, such as storage 315 or 325), and input and output devices 410. In various implementations, storage memory 408 can be one or more of: local devices, interfaces to remote storage devices, or combinations thereof. For example, storage memory 408 can be a set of one or more hard drives (e.g., a redundant array of independent disks (RAID)) accessible through a system bus or can be a cloud storage provider or other network storage accessible via one or more

communications networks (e.g., a network accessible storage (NAS) device, such as storage 315 or storage provided through another server 320). Components 400 can be implemented in a client computing device such as client computing devices 305 or on a server computing device, such as server computing device 310 or 320.

[0104] General software 420 can include various applications including an operating system 422, local programs 424, and a basic input output system (BIOS) 426. Specialized components 440 can be subcomponents of a general software application 420, such as local programs 424. Specialized components 440 can be for providing patient-specific healthcare data can include an authentication module 444, EMR module 446, account linking module 448, patient treatment data module 450, integration module 452, and components which can be used for providing user interfaces, transferring data, and controlling the specialized components, such as interfaces 442 (e.g., user interface on tablet, smartphone, laptop, etc.). In some implementations, components 400 can be in a computing system that is distributed across multiple computing devices or can be an interface to a server-based application executing one or more of specialized components 440. Although depicted as separate components, specialized components 440 may be logical or other nonphysical differentiations of functions and/or may be submodules or code-blocks of one or more applications.

[0105] Authentication module 444 provides authentication management of patient-specific healthcare data to users (e.g., patients, family members, healthcare providers, approved users, etc.). Authentication module 444 can manage the access (e.g., read-only, editing capability, privacy protecting, etc.) to the healthcare data (e.g., surgical plan, virtual model, etc.) based on geolocation, biometrics, blockchain, token, or key functionality for user authentication. Authentication module 444 provides token functionality for user authentication to access the healthcare data. Authentication module 444 can generate a token for the user to access medical records. In some implementations, the token is valid for a threshold of time during which the user can access the medical records. A user can request and receive a token from the authentication module 444. In some implementations, authentication module 444 provides key functionality for user authentication to access the healthcare data. The authentication module 444 can share an authentication key (e.g., symmetric or asymmetric key) with the user over a secure channel for the user to access the healthcare data during the time of authentication.

[0106] Authentication module 444 provides biometric functionality for user authentication to access the healthcare data. A user can provide their biometric information (e.g., voice, facial scan, fingerprint, iris scanning, dental records, height, weight, etc.) to the authentication module 444. The authentication module 444 can store the biometric information. When the user attempts to access the healthcare data, the authentication module 444 can verify the identity of the user based on the biometric information before granting the user access to medical records. In some cases, the authentication module 444 requires the user to provide two or more types of biometric information, such as a fingerprint and voice, before granting the user access to the medical records.

[0107] Authentication module 444 provides geolocation functionality for user authentication to access the healthcare data. Authentication module 444 can verify the location of the user device attempting to access the healthcare data, when determining to permit a user to access healthcare data. In an example, a healthcare provider can only access a patient's medical records at a healthcare facility. In another example, a healthcare provider can only access the patient's medical records when the patient is at the healthcare facility of the healthcare provider.

[0108] Authentication module 444 provides blockchain functionality for user authentication to access the healthcare data. The authentication module 444 allows for the creation of a new block for a new/existing blockchain distributed ledger, hashing of the new block, and addition of the new block to the patient's private blockchain and distributed ledger. The authentication module 444 can manage a plurality of public blockchains, private blockchains, and/or other distributed ledgers for patients. In some implementations, the privacy of each patient's blockchain(s) can be ensured because each patient maintains an individual blockchain and/or ledger for the patient's medical records and data. In other implementations, transactions include a public key that matches a private key associated with the patient. In these implementations, while the transactions are added to a public ledger, details of the transactions can only be accessed when the private key is used, ensuring patient data privacy.

[0109] New blocks for blockchains and/or ledgers are based on received EMRs from the EMR module 446. In some implementations, the created blockchain ledger(s) can be stored in persistent memory of an implant of the patient. In other implementations,

the created blockchain ledger(s) can be stored in memory associated with the system and may be a private blockchain ledger associated exclusively with the patient or a public blockchain ledger associated with a group of patients. If the blockchain ledger is a public ledger, each block can be associated with different patients, but cannot be accessed for viewing unless a medical professional possesses a private key associated with the patient identified in a particular block in the ledger. Groups of patients can be subdivided in multiple ways. For example, a group of patients can be defined as all patients at a particular medical facility, all patients under the treatment of a particular medical professional, all patients covered by a particular medical insurance provider, all patients with a similar pathology, treatment, outcome, and the like.

[0110] Authentication module 444 can authenticate a user with a multi-factor identification, such as requiring two types of authentication from an authentication group which includes blockchain, biometric, token, key, and geolocation types of authentication. Authentication module 444 can adjust the authentication requirements based on the user health metrics. For example, if the user's heart rate is below a threshold level (e.g., indicating the user is experiencing a medical emergency), the authentication module 444 requires lower levels of authentication by a healthcare provider to access the patient's medical records. Adjusting the level of authentication, allows healthcare provides (e.g., surgeon, EMT, etc.) to access medical information while treating the user during the medical emergency. Authentication module 444 can require various levels of security based on the type of medical information in the medical records. For example, health metrics, such as blood pressure or heart rate from a wearable device, require lower authentication levels to access than patient health history or medical insurance information.

[0111] EMR module 446 maintains patient electronic medical records. The EMRs can include patient healthcare data (e.g., images, scans, etc.), demographic information about the patient, identifying information of the patient, historical patient treatment data, metrics, plans (e.g., pre-operative plans, corrective plans, surgical plans, post-operative plans, etc.), data providing pathology-related information, provider information (e.g., physician, hospital, surgical team, etc.), patient feedback (e.g., feedback acquired using quality of life questionnaires, surveys, patient-reported outcome measures, etc.), vital signs, diagnostic results, and/or other medically relevant information about the patient, such as family history of various illnesses or medical problems, prescription drug history,

and the like. EMR module 446 can also maintain patient treatment records, such as medical procedures undergone, implant information (e.g., patient-specific design, composition, implantation date, manufacture, etc.), drug therapies performed, clinical trials participated in, and other relevant medical actions taken on behalf of the health of the patient. Each medical action can also include various additional data points, such as attending physician, prescribing physician, time and date of action, patient medical reaction, medical action taken, and other relevant medical data points. In some implementations, EMRs can also include various relevant images and scans (e.g., CT scans, 3D CT scans, CMCT scans, MRIs, PET scans, etc.), images (e.g., X-ray images, magnetic resonance imaging, ultrasound images, etc.) associated with medical actions, such as medical images, blood test results, and the like. The EMR module 446 can provide EMRs to the authentication module 444 for generating transactions based on the EMRs. EMR module 446 manages the medical records of the user, such as implant data, surgical plans, health records, or medical insurance information. EMR module 446 can detect updates for the user medical records and implement the updates into the medical records. For example, EMR module 446 detects a family member is added to the medical insurance plans and updates the medical records to include the additional family member.

[0112] Account linking module 448 links the accounts between healthcare providers, family members, banking accounts, credit card accounts, insurance providers, government entities, or any account providing information to the implant (user accounts), healthcare analytic cloud, digital filing cabinet, or healthcare provider. A user (e.g., patient or healthcare provider) can provide authentication credentials (e.g., usernames, passwords, pins, etc.) for their accounts to account linking module 448. In some implementations, account linking module 448 identifies accounts the user needs to provide, such as insurance accounts, healthcare history accounts, or payment accounts, so the system can provide service to the user.

[0113] Patient treatment data module 450 gathers patient data regarding a medical event or medical action (e.g., a hospitalization, a medical procedure, a drug therapy regime, and the like) from various medical systems. In one example, patient treatment data module 450 can receive identifying information identifying a patient, a result from a routine physician visit, and any relevant data associated with the visit, such as various medical images taken, blood pressure values, heart rate, blood oxygen levels, body mass

index, and/or other medical data. The patient treatment data module 450 can provide this data in an EMR to the EMR module 444 to create new EMRs for patients.

[0114] Integration module 452 integrates input sources of a patient healthcare data. The input sources can include healthcare data digital filing cabinets, wearable devices, patient implants, healthcare provider devices, cloud-based analytic devices, or patient devices.

[0115] Specialized components 460 for analyzing patient-specific healthcare data can include a notification module 464, integration module 466, post-operative analytics module 468, machine learning module 470, and components which can be used for providing user interfaces, transferring data, and controlling the specialized components, such as interfaces 462. In some implementations, components 400 can be in a computing system that is distributed across multiple computing devices or can be an interface to a server-based application executing one or more of specialized components 460. Although depicted as separate components, specialized components 460 may be logical or other nonphysical differentiations of functions and/or may be submodules or code-blocks of one or more applications.

[0116] Notification module 464 provides alerts based on events identified from healthcare data inputted into digital filing cabinet. For example, the alerts are user (e.g., physician, Doctor, patient etc.) notifications from monitoring data collected from wearable devices. The notification module 446 can generate an alert to request additional or updated patient information, scheduling appointments, notifying of emergencies, etc. For example, the notification module 464 can generate an alert when the patient's health metrics (e.g., heart rate, blood pressure, body temperature, etc.) are outside of healthy metric threshold (e.g., a threshold or range determined by a healthcare provider).

[0117] Integration module 466 integrates information from the healthcare providers (e.g., surgical, physical therapy, etc.) and health insurance providers with patient information. In some implementations, integration module 466 identifies new healthcare data (e.g., medical charts, medical images, health goals, medical diagnostics, etc.) added to the digital filing cabinet and updates the organized healthcare data with the new healthcare data.

[0118] Post-operative analytics module 468 collects and analyses patient information, patient goals, healthcare provider goals for a patient, outcomes of a medical

procedure, health metric goals (e.g., BMI, blood pressure, etc.). For example, after a medical procedure, the post-operative analytics module 468 analyzed x-ray images to determine whether the medical procedure was successful. The post-operative analytics module 468 can determine whether the patient should attend physical therapy based on collected health metrics, such as patient mobility (e.g., range of motion of limbs or fingers).

[0119] Machine learning module 470 may be configured to analyze user healthcare data in a digital filing cabinet to determine to notify the events (e.g., emergencies, appointments, health goals, etc.). The machine learning module 470 may be configured to analyze healthcare data based on at least one machine-learning algorithm trained on at least one dataset reflecting a user's healthcare information, goals, and health status. The at least one machine-learning algorithms (and models) may be stored locally at databases and/or externally at databases (e.g., cloud databases and/or cloud servers). Client devices may be equipped to access these machine learning algorithms and intelligently analyze healthcare data and notify a user based on at least one machine learning model that is trained on a user's historical healthcare data. For example, if a user frequently has increased blood sugar levels, the user's health metrics may be collected to train a machine learning model to then automatically notify the user to exercise to help lower the user's blood sugar.

[0120] As described herein, a machine-learning (ML) model may refer to a predictive or statistical utility or program that may be used to determine a probability distribution over one or more character sequences, classes, objects, result sets or events, and/or to predict a response value from one or more predictors. A model may be based on, or incorporate, one or more rule sets, machine learning, a neural network, or the like. In examples, the ML models may be located on the client device, service device, a network appliance (e.g., a firewall, a router, etc.), or some combination thereof. The ML models may process user healthcare data and other data stores of user health metrics to determine when to generate a notification for user. Based on an aggregation of data from a user's healthcare digital filing cabinet, wearable devices, and other user data stores, at least one ML model may be trained and subsequently deployed to automatically generate healthcare notifications. The trained ML model may be deployed to one or more devices. As a specific example, an instance of a trained ML model may be deployed to a server device and to a client device. The ML model deployed to a server device may be configured to be used by the client device when, for example, the client

device is connected to the Internet. Conversely, the ML model deployed to a client device may be configured to be used by the client device when, for example, the client device is not connected to the Internet. In some instances, a client device may not be connected to the Internet but still configured to receive satellite signals with healthcare data. In such examples, the ML model may be locally cached by the client device. In some implementations, the machine learning module 470 identifies new healthcare data in the digital filing cabinet and updates the health goals or metrics of the patient based on the new healthcare data.

[0121] Specialized components 480 for managing patient-specific healthcare data by a healthcare provider can include an integration module 484, post-operative analytics module 486, control module 488, point of care module 490 and components which can be used for providing user interfaces, transferring data, and controlling the specialized components, such as interfaces 482. In some implementations, components 400 can be in a computing system that is distributed across multiple computing devices or can be an interface to a server-based application executing one or more of specialized components 480. Although depicted as separate components, specialized components 480 may be logical or other nonphysical differentiations of functions and/or may be submodules or code-blocks of one or more applications.

[0122] Integration module 484 integrates patient healthcare data from digital filing cabinets (e.g., data stored on patient implants, data from wearable devices, patient EMRs, data stored on healthcare provider devices, etc.) into physician managed analytics. The integration module 484 can process the collected healthcare data and identify information for the healthcare providers to review. For example, the integration module 484 can identify patient health metrics which indicate the user needs a health plan, such as lose weight, lower blood sugar levels, or a nutritional diet.

[0123] Post-operative analytics module 486 collects and analyses patient information, patient goals, outcomes of a medical procedure, healthcare provider notes from procedures or patient exams. The post-operative analytics module 486 can identify EMRs that a healthcare provide should review, such as new spots in an MRI which can indicate cancer.

[0124] Control module 488 controls the patient healthcare data in the healthcare provider digital filing cabinet. The control module 488 can determine automated settings

for searching, periodically or continually, for additional data to add to the digital filing cabinet. Control module 488 can manage the privacy of the healthcare data by requiring authentication credentials (as described in authentication module 444) of any user attempting to access the patient healthcare data. In some implementations, the control module 488 encrypts the patient healthcare data. Control module 488 can identify new healthcare data and update the digital filing cabinet of the healthcare provider to include the new healthcare data.

[0125] Point of care (POC) module 490 identifies POC devices, such as healthcare provider devices (e.g., medical instruments, charting devices, patient monitoring devices, etc.) or patient devices (e.g., wearable devices, implants, smartphones, etc.) and retrieves collected data from POC devices. The POC module 490 can collect health history data, treatment data, health metrics of the patient, the geolocation of the patient, insurance information, biometric data, or payment information from the POC devices. The POC module 490 can display versions of the health data on a user device for a healthcare provider to show a patient. For example, the POC module 490 displays x-ray images on a user interface so the patient can see an implant after a surgery procedure.

[0126] FIG. 5 is a flow diagram illustrating a process 500 for patient-specific healthcare data from an implant, according to an embodiment. At step 502, process 500 links accounts from multiple entities (e.g., healthcare providers, hospitals, medical clinics, insurance companies, patient social media accounts, etc.) into a digital filing cabinet. In some implementations, the digital filing cabinet is in an implant in a patient. A patient can provide authentication credentials (e.g., usernames, passwords, etc.) for the accounts providing data to the digital filing cabinet. Inputs to the digital filing cabinet can be from various healthcare providers (radiology, surgery, emergency, cardiology, etc.) and directly from diagnostic or treatment systems (imaging, pathology, pharmacy, etc.).

[0127] At step 504, process 500 integrates input sources of the patient healthcare data. The input sources can include wearable devices, patient implants, healthcare provider devices, cloud-based analytic devices, storage devices, or patient devices.

[0128] At step 506, process 500 receives healthcare data (e.g., EMRs) of a patient. The healthcare data can include data representative of the patient's condition, anatomy, pathology, symptoms, medical history, preferences, and/or any other information or parameters relevant to the patient. For example, the healthcare data can include surgical

intervention data, treatment outcome data, progress data (e.g., surgeon notes), patient feedback (e.g., feedback acquired using quality of life questionnaires, surveys), clinical data, patient information (e.g., demographics, sex, age, height, weight, type of pathology, occupation, activity level, tissue information, health rating, comorbidities, health related quality of life (HRQL)), vital signs, diagnostic results, medication information, allergies, diagnostic equipment information (e.g., manufacturer, model number, specifications, user-selected settings/configurations, etc.) or the like. The healthcare data can also include image data, such as camera images, Magnetic Resonance Imaging (MRI) images, ultrasound images, Computerized Aided Tomography (CAT) scan images, Positron Emission Tomography (PET) images, X-Ray images, and the like. In some embodiments, the healthcare data includes data representing one or more of patient identification number (ID), age, gender, body mass index (BMI), lumbar lordosis, Cobb angle(s), pelvic incidence, disc height, segment flexibility, bone quality, rotational displacement, and/or treatment level of the spine. The healthcare data can be received at a server, computing device, or other computing system. For example, in some embodiments the patient data set can be received by the server 106 shown in FIG. 1.

[0129] In some embodiments, the received patient data set can include disease metrics, such as lumbar lordosis, Cobb angles, coronal parameters (e.g., coronal balance, global coronal balance, coronal pelvic tilt, etc.), sagittal parameters (e.g., pelvic incidence, sacral slope, thoracic kyphosis, etc.) and/or pelvic parameters. The disease metrics can include micro-measurements (e.g., metrics associated with specific or individual segments of the patient's spine) and/or macro-measurements (e.g., metrics associated with multiple segments of the patient's spine). In some embodiments, the disease metrics are not included in the patient data set, and the method 500 includes determining (e.g., automatically determining) one or more of the disease metrics based on the patient image data, as described below.

[0130] At step 508, process 500 stores the healthcare data in the digital filing cabinet. The computing system that receives the healthcare data in step 506 can also store one or more software modules (e.g., the data analysis module 116 shown in FIG. 1, or additional software modules for performing various operations of the process 500).

[0131] Using the healthcare data, process 500 can create a virtual model of the patient's native anatomical configuration (also referred to as "pre-operative anatomical

configuration"). The virtual model can be based on the image data included in the patient data set received in step 506. For example, the same computing system that received the patient data set in step 506 can analyze the image data in the patient data set to generate a virtual model of the patient's native anatomical configuration. The virtual model can be a two- or three-dimensional visual representation of the patient's native anatomy. The virtual model can include one or more regions of interest, and may include some or all of the patient's anatomy within the regions of interest (e.g., any combination of tissue types including, but not limited to, bony structures, cartilage, soft tissue, vascular tissue, nervous tissue, etc.). As a non-limiting example, the virtual model can include a visual representation of the patient's spinal cord region, including some or all of the sacrum, lumbar region, thoracic region, and/or cervical region. In some embodiments, the virtual model includes soft tissue, cartilage, and other non-bony structures. In other embodiments, the virtual model only includes the patient's bony structures. An example of a virtual model of the native anatomical configuration is described below with respect to FIGS. 8A and 8B.

[0132] Process 100 can create a virtual model of a corrected anatomical configuration (which can also be referred to herein as the "planned configuration," "optimized geometry," "post-operative anatomical configuration," or "target outcome") for the patient. For example, the computing system can, using the analysis procedures described previously, determine a "corrected" or "optimized" anatomical configuration for the particular patient that represents an ideal surgical outcome for the particular patient. This can be done, for example, by analyzing a plurality of reference patient data sets to identify post-operative anatomical configurations for similar patients who had a favorable post-operative outcome, as previously described in detail with respect to FIGS. 1-4 (e.g., based on similarity of the reference patient data set to the patient data set and/or whether the reference patient had a favorable treatment outcome). This may also include applying one or more mathematical rules defining optimal anatomical outcomes (e.g., positional relationships between anatomic elements) and/or target (e.g., acceptable) post-operative metrics/design criteria (e.g., adjust the anatomy so that the post-operative sagittal vertical axis is less than 7mm, the post-operative Cobb angle is less than 10 degrees, etc.). Target post-operative metrics can include, but are not limited to, target coronal parameters, target sagittal parameters, target pelvic incidence angle, target Cobb angle, target shoulder tilt, target iliolumbar angle, target coronal balance, target Cobb

angle, target lordosis angle, and/or a target intervertebral space height. The difference between the native anatomical configuration and the corrected anatomical configuration may be referred to as a “patient-specific correction” or “target correction.”

[0133] Once the corrected anatomical configuration is determined, the computing system can generate a two- or three-dimensional visual representation of the patient's anatomy with the corrected anatomical configuration. The virtual model of the patient's corrected anatomical configuration can include one or more regions of interest, and may include some or all of the patient's anatomy within the regions of interest (e.g., any combination of tissue types including, but not limited to, bony structures, cartilage, soft tissue, vascular tissue, nervous tissue, etc.). As a non-limiting example, the virtual model can include a visual representation of the patient's spinal cord region in a corrected anatomical configuration, including some or all of the sacrum, lumbar region, thoracic region, and/or cervical region. In some embodiments, the virtual model includes soft tissue, cartilage, and other non-bony structures. In other embodiments, the virtual model only includes the patient's bony structures. An example of a virtual model of the native anatomical configuration is described below with respect to FIGS. 9A-1-9B-2.

[0134] Images of the patient can be segmented to isolate separate anatomic elements of the anatomy of interest. The spatial relationships between the isolated anatomic elements can be modified to generate a target or corrected patient pathology. The modifications can be selected based on regulatory criteria, financial parameters, etc. Other techniques can be used to generate anatomical configurations based on the available patient data.

[0135] Process 500 can generate (e.g., automatically generating) a surgical plan for achieving the corrected anatomical configuration shown by the virtual model. The surgical plan can include pre-operative plans, operative plans, post-operative plans, and/or specific spine metrics associated with the optimal surgical outcome. For example, the surgical plans can include a specific surgical procedure for achieving the corrected anatomical configuration. In the context of spinal surgery, the surgical plan may include a specific fusion surgery (e.g., PLIF, ALIF, TLIF, LLIF, DLIF, XLIF, etc.) across a specific range of vertebral levels (e.g., L1-L4, L1-5, L3-T12, etc.). Of course, other surgical procedures may be identified for achieving the corrected anatomical configuration, such as non-fusion surgical approaches and orthopedic procedures for other areas of the

patient. The surgical plan may also include one or more expected spine metrics (e.g., lumbar lordosis, Cobb angles, coronal parameters, sagittal parameters, and/or pelvic parameters) corresponding to the expected post-operative patient anatomy. The surgical plan can be generated by the same or different computing system that created the virtual model of the corrected anatomical configuration. In some embodiments, the surgical plan can also be based on one or more reference patient data sets as previously described with respect to FIGS. 1-4. In some embodiments, the surgical plan can also be based at least in part on surgeon-specific preferences and/or outcomes associated with a specific surgeon performing the surgery. In some embodiments, more than one surgical plan is generated to provide a surgeon with multiple options. An example of a surgical plan is described below with respect to FIGS. 10A-13. A user (e.g., healthcare provider, patient, etc.) can modify the surgical plan based on their access level (e.g., described in authentication module 444). At step 510, process 500 manages access to the healthcare data. Process 500 can determine to allow a user to access the healthcare data based on an authentication level. A user can provide authentication credentials which include usernames, passwords, pin numbers, biometric data, geolocation data, tokens, or keys. Process 500 can encrypt or censor patient personal identifiable information (PII) to protect the identity of the user.

[0136] At step 512, process 500 receives a request, from a user (e.g., patient, healthcare provider, insurance representative, etc.), to access the healthcare data.

[0137] At step 514, process 500 determines the authentication level of the user. The authentication level of the user is based on geolocation of the user, biometrics, blockchain or authentication credentials. In some implementations, process 500 uses two-factor authentication when determining the authentication level of the user. For example, process 500 requires two or more of the geolocation data, biometric data, blockchain, tokens, keys, or authentication credentials, before granting the user access to the healthcare data.

[0138] At step 516, process 500 determines the amount of healthcare data to provide based on the authentication level. Based on the authentication level, the user is granted read-only capabilities, editing capabilities, or the capability to view all or some of the healthcare data. For example, a patient can view all their own healthcare data and

personal information (e.g., SSN, banking information, insurance information, etc.) but a healthcare provider is limited to patient health history information.

[0139] At step 518, process 500 transmits the healthcare data based on the authentication level to a user interface of the user. The implant can include wireless chip (e.g., Bluetooth chip or Near Field Communication (NFC) chip) so that the user interface can wirelessly receive the healthcare data. Process 500 can transmit the healthcare data in an encrypted format and the user can decrypt the healthcare data. In some implementations, process 500 can generate and transmit a code (e.g., QR, RFID, etc.) that a user can scan to access healthcare data on the implant.

[0140] The process 500 can be used to automatically share healthcare data to enable, for example, model training (e.g., machine learning training), patient analytics, healthcare treatment modifications, event notification, or combinations thereof. In some implementations, step 504 can be used to integrate data from multiple input sources discussed in connection with FIG. 1, such as the manufacturing system 124, implant 150, analytics integration platform 126, and/or server 106. The digital filing cabinet 180 of FIG. 1 can store healthcare data that is automatically sent to the server 106 to, for example, update the database 110 of FIG. 1, train machine learning models based on newly available patient data, or the like. If the database 110 receives a patient identifier and image, the digital filing cabinet 180 can associate the image with a medical procedure. The database 110 can then send the image and any associated data to the server 106. The server 106 can identify the newly available scan and incorporate it into training sets, a patient EMR, or the like. In some embodiments, the server 106 can compare a newly available scan to one or more previous scans to identify changes in a patient's condition. The system 100 can score the change and if it exceeds a threshold event score, the system 106 can send notification indicating that an adverse event has occurred. The system 100 of FIG. 1 can use process 500 to continuously monitor and track patient data while also adaptively modifying analytics to incorporate newly available data over periods of time. In some embodiments, the system 100 can share data directly between subsystems without the use of digital filing cabinets.

[0141] In some embodiments, the process 500 of FIG. 5 can be used to manage healthcare data by linking to patient-managed accounts that can include digital filing cabinets, cloud storage accounts, etc. A system can receive patient data from one or

more of the patient-managed accounts and can analyze the received patient data to identify one or more relevant training parameters. The system can generate a reference data set with the received patient data based on the one or more relevant training parameters. The system can modify or generate reference data sets with newly available patient data. In some embodiments, the system can request access to the data at step 512. A user can confirm that the healthcare provider should have access to the newly available data.

[0142] The healthcare provider can train one or more machine learning models based at least in part on the reference data set and then use the newly trained machine learning models to design implants similar to the patient-specific implant. In some embodiments, the patient-managed account can send a limited amount of data identified suitable for machine learning models. At step 516, for example, the patient-managed account can determine an amount and type of information to send to a training system to train one or more machine learning models for future implant design, surgical plan generation, or the like. The data can then be transmitted from the patient-managed account to the healthcare provider or implant manufacturer system. The relevant training parameter can be categorized based on the patient's condition.

[0143] For spinal treatments, the relevant training parameter can categorize the patient's spinal condition based on one or more predetermined thresholds, such as threshold level of lumbar lordosis, Cobb angle, pelvic incidence, disc height, or other spinal parameters. After treatment, disease progression can cause changes in the parameters. By receiving additional patient data over long periods of time, the system can identify patients with successful outcomes, even with disease progression, and use the post-operative patient data obtained over periods of time to train machine learning models for designing surgical plans for new patients. The system can compare received patient data to pre-operative data of the patient to evaluate disease progression.

[0144] In some embodiments, the systems can identify patient data for reference data sets for machine learning training based on the comparisons. In some implementations, the system can determine an outcome score for a patient based on the received patient data. In response to the outcome score exceeding a threshold score, the patient data can be used to train one or more machine learning models to generate a patient-specific surgical plan. The physician or healthcare provider can modify or input

threshold scores, algorithms for determining outcome scores, manually inputting outcome scores (e.g., based on physician diagnosis), or the like. In some embodiments, the system disclosed herein can receive patient data and determine whether the patient data meets one or more criteria for training models. The systems can analyze patient images to determine whether they provide sufficient resolution accuracy for analytics. The system can automatically modify models in response to receipt of additional patient data that meets confidence scores.

[0145] FIG. 6 is a flow diagram illustrating a process 600 for analyzing patient-specific medical data from an implant, according to an embodiment. At step 602, process 600 integrates healthcare data from multiple entities (e.g., healthcare providers, hospitals, medical clinics, insurance companies, patient social media accounts, etc.) and sources. The sources can include wearable devices, patient implants, healthcare provider devices, cloud-based analytic devices, storage devices, or patient devices

[0146] At step 604, process 600 receives post-operative healthcare data and updates the healthcare data with the post-operative healthcare data.

[0147] At step 606, process 600 analyzes the healthcare data. Process 600 can identify a manufacturer of the implant and determine whether the implant has an update or a recall from the manufacture. Process 600 can generate a notification and send the notification to user device to alert the patient or healthcare provider of the recall or update to the implant. Process 600 can analyze the healthcare data and identify differences in various healthcare providers (e.g., surgeon, therapist, family doctor, etc.) advice or documentation of the patient. For example, healthcare providers, such as a surgeon or physical therapist, can provide conflicting guidance to a patient. Process 600 can identify the conflicting guidance and alert the user to seek clarification on which guidance to follow.

[0148] At step 608, process 600 identifies patient information and health goals from the healthcare data. The health goals can include health metrics (e.g., BMI, blood pressure, blood sugar, etc.) that a healthcare provider determines for the patient or the patient sets for themselves. In some implementations, process 600 identifies an insurance claim associated with the patient in the healthcare data and scraps information from the insurance claim that requires patient involvement (e.g., paying a fee, providing information, signing a form, etc.). Process 600 can compare the patient healthcare goals

provided by the patient with the patient healthcare goals provided by a healthcare provider of the patient and identify differences between the patient healthcare goals provided by the patient with the patient healthcare goals provided by the healthcare provider of the patient. In some implementations, process 600 identifies (e.g., using AI or ML) new healthcare data and updates the patient's medical records and/or health goals.

[0149] At step 610, process 600 determines whether collected health metrics (e.g., heart rate, blood pressure, oxygen rate, body temperature, etc.) are outside of a health range. If the collected health metrics are within the determined health range, process 600 can continue to analyze the healthcare data.

[0150] If the health metrics are outside the health range, at step 612, process 600 generates a notification to alert the patient of potential health risk and provide guidance. For example, the notification can include diet instructions, exercise instructions, the captured health metrics, or any guidance for the patient. The process 600 can be used to display vitals, medical records, health goals, and notifications on a user database (e.g., database 110) for the user to select and view, as illustrated in FIG. 11. In some embodiments, process 600 sends the notification to family members of the patient or healthcare providers of the patient. Process 600 can determine the recipients of the notification based on the type of health metrics. For example, when the blood pressure metrics of a diabetic patient reach a threshold point, process 600 notifies family members or healthcare providers since the patient may need medical attention.

[0151] FIG. 7 is a flow diagram illustrating a process 700 for managing patient-specific healthcare data by a healthcare provider, according to an embodiment. At step 702, process 700 integrates healthcare data into healthcare provider analytics in a digital filing cabinet. The healthcare provider analytics can review patient healthcare data and identify needed procedures or appointments.

[0152] At step 704, process 700 adds post-operative healthcare data to the healthcare provider digital filing cabinet.

[0153] At step 706, process 700 manages the healthcare data. Process 700 can identify data that is needed for a complete patient review. For example, process 700 can identify if blood samples, medical treatment data, or patient medical history information is missing from a patient file. Process 700 can notify the healthcare provider of the

missing information. In some implementations, process 700 manages billings for the healthcare provider by identifying patient accounts who have not paid for healthcare services.

[0154] At step 708, process 700 generates healthcare plan for the patient. The healthcare plan can include a patient diet, health goals (e.g., weight, BMI, blood pressure, etc.), physical therapy plans, or exercise plans for the patient. Process 700 can generate images or messages that a healthcare provider can share with a patient.

[0155] At step 710, process 700 determines whether there is additional healthcare data collected from the data sources. When there is additional data to analyze, process 700 an return to step 706 and analyze the additional data.

[0156] When there is no additional data, at step 712, process 700 generates a viewable version of the healthcare data for the patient to access. Process 700 can provide the patient with current health metrics (e.g., heart rate, blood pressure, etc.) or medical images (e.g., MRI or x-ray images). For example, process 700 can send the patient medical images of before and after a surgery to illustrate where an implant was place, or a bone was reset.

[0157] The systems/devices 100, 200, 300, 400 can perform one or more steps of the methods discussed in connection with FIGS. 5-7. For example, the systems and components can perform various steps and methods described in connection with FIGS. 5-7 in other steps and methods disclosed herein. Thus, although certain operations are discussed in connection with FIGS. 5-7 for specific components, other components and systems disclosed herein can be incorporated into or operate with the other components disclosed herein.

[0158] The computing systems disclosed herein can store and access pathology data (e.g., pre-operative pathology data, planned post-operative pathology, post-operative outcome pathology, etc.), anatomical data (e.g., scans, X-rays, etc.), virtual model data (e.g., images of two-dimensional models, images of three-dimensional models, etc.), and other healthcare-related data, including data discussed in connection with methods disclosed herein (e.g., method 500 of FIG. 5, method 600 of FIG. 6, method 700 of FIG. 7, etc.). The computing systems can provide interactive interfaces or displays for coordinating viewing, modification, and/or approval by users. The users can be patients, approved individuals (e.g., family members), healthcare providers,

manufactures, etc. The data can be synchronized in real-time, near-real time, or at another time (e.g., user-set time) based on, for example, one or more of user authorization, control lists, one or more synchronization settings (e.g., data types for synchronization, frequency of synchronization, etc.), user feedback (e.g., user approval or modification), etc. For control list or authorization level synchronization, plans or reports can be synchronized with other plans or reports based on authorization levels or control lists to synchronize surgical plans viewable by multiple users. This allows plans or reports to be stored by different digital filing cabinets with individualized levels of security. The treatment plans for patients may have different amounts of information and levels of security than treatment plans for health care providers, such as surgeons or surgical teams. Example data is discussed in connection with FIGS. 8-11, example data viewing via interactive technology is discussed in connection in with FIGS. 10A-10B, and example treatment plans are discussed in connection in with FIG. 11.

[0159] FIGS. 8A and 8B illustrate an example of a virtual model 800 of a patient's native anatomical configuration. In particular, FIG. 8A is an enlarged view of the virtual model 800 of the patient's native anatomy and shows the patient's native anatomy of their lower spinal cord region. The virtual model 800 is a three-dimensional visual representation of the patient's native anatomy. The virtual model 800 can be stored in digital filing cabinets (e.g., digital filing cabinet 180 of FIG. 1), analyzed by the analysis system (e.g., analysis system 106 of FIG. 1), and transmitted/viewed via a network. Each component can utilize a security protocol selected for that component. The computing system 100 can update the virtual model 800 with collected patient data. For example, as a patient gains weight, loses weight, exercises, rehabilitates, progresses during a disease, recovers from injuries, or any activity, the virtual model 800 can change to accurately represent the current patient anatomy. System 100 can update the virtual model based on image data (e.g., X-ray images, CT scans, MRI scans, etc.) that is collected during pre-operative, intra-operative, and post-operative procedures of a patient.

[0160] In the illustrated embodiment, the virtual model includes a portion of the spinal column extending from the sacrum to the L4 vertebral level. The virtual model can include other regions of the patient's spinal column, including cervical vertebrae, thoracic vertebrae, lumbar vertebrae, and the sacrum. The illustrated virtual model 800 only

includes bony structures of the patient's anatomy, but in other embodiments may include additional structures, such as cartilage, soft tissue, vascular tissue, nervous tissue, etc.

[0161] FIG. 8B illustrates a virtual model display 850 (referred to herein as the "display 850") showing different views of the virtual model 800. The virtual model display 850 includes a three-dimensional view of the virtual model 800, one or more coronal cross-section(s) 802 of the virtual model 800, one or more axial cross section(s) 804 of the virtual model 800, and/or one or more sagittal cross-section(s) 806 of the virtual model 800. A user can rotate, zoom in, zoom out, annotate, or alter the virtual model 800. Of course, other views are possible and can be included on the virtual model display 850. In some embodiments, the virtual model 800 may be interactive such that a user can manipulate the orientation or view of the virtual model 800 (e.g., rotate), change the depth of the displayed cross-sections, select and isolate specific bony structures, change the relative position of anatomic elements, define model parameters (e.g., parametric relationships), or the like.

[0162] In some embodiments, the virtual model can represent or include, for example, a hip, knee, jaw, hand, shoulder, elbow, skull, foot, ankle, organ, vascular feature, etc. The virtual model can be used to generate a patient-specific treatment procedure, such as an orthopedic surgery procedure, such as spinal surgery, hip surgery, knee surgery, jaw surgery, hand surgery, shoulder surgery, elbow surgery, total joint reconstruction (arthroplasty), skull reconstruction, foot surgery, or ankle surgery. The number, types, and details of virtual models (e.g., resolution of images/models, anatomic accuracy of anatomic elements, etc.) can be selected based on patient-specific treatment procedure(s) to be performed. The virtual model can be a two-dimensional or three-dimensional virtual model and can include, for example, CAD data, material data, surface modeling, manufacturing data, regulatory data, or the like. The CAD data can include, for example, solid modeling data (e.g., part files, assembly files, libraries, part/object identifiers, etc.), model geometry, object representations, parametric data, object representations, topology data, surface data, assembly data, metadata, etc. The material data can include, for example, material properties, material type, material manufacturing data (e.g., acceptable manufacturing techniques, manufacturing steps, etc.), or the like. The regulatory data can include, for example, governmental regulatory requirements, reimbursement requirements, etc. The object representations can be polygonal representations, boundary representations, etc. The features of the virtual model can be

selected based on, for example, the modeling software/hardware, treatment procedure, manufacturing parameters, or the like.

[0163] FIG. 8C illustrates an example of a healthcare data set 880 (e.g., as received in step 506 of FIG. 5) that can be generated by process 700. The healthcare data 880 can include any of the information previously described with respect to healthcare data. For example, the healthcare data 700 includes patient information (e.g., patient identification no., patient MRN, patient name, sex, age, body mass index (BMI), surgery date, surgeon, etc.), diagnostic information (e.g., Oswestry Disability Index (ODI), VAS-back score, VAS-leg score, pre-operative pelvic incidence, pre-operative lumbar lordosis, pre-operative PI-LL angle, pre-operative lumbar coronal cobb, etc.), and image data 882 (x-ray, CT, MRI, etc.). The interface can include, without limitation, instructions, prompts, selection menus, drop down lists, and other selectable features for managing input, such as user feedback, image data (e.g., how to upload data, such as images), studies (e.g., image studies), etc.

[0164] FIGS. 9A-1-9B-2 demonstrate an example of a virtual model of a patient's native anatomical configuration (e.g., as created process 500) and a virtual model of the patient's corrected anatomical configuration (e.g., as created in step 504 of the method 500). In particular, FIGS. 9A-1 and 9A-2 are anterior and lateral views, respectively, of a virtual model 910 showing a native anatomical configuration of a portion of a patient's spine, and FIGS. 9B-1 and 9B-2 are anterior and lateral views, respectively, of a virtual model 920 showing the corrected anatomical configuration for the same patient. Referring first to FIG. 9A-1, the anterior view of the virtual model 910 illustrates the patient has abnormal curvature (e.g., scoliosis) of their spinal column. This is marked by line X, which follows a rostral-caudal axis of the spinal column. Referring next to FIG. 9A-1, the lateral view of the virtual model 910 illustrates the patient has collapsed discs or decreased spacing between adjacent vertebral endplates, marked by ovals Y. FIGS. 9B-1 and 9B-2 illustrate the corrected virtual model 920 accounting for the abnormal anatomical configurations shown in FIGS. 9A-1 and 9A-2. For example, FIG. 9B-1, which is an anterior view of the virtual model 920, illustrates the patient's spinal column having corrected alignment (e.g., the abnormal curvature has been reduced). This correction is shown by line X, which also follows a rostral-caudal axis of the spinal column. FIG. 9B-2, which is a lateral view of the virtual model 920, illustrates the patient's spinal column having restored disc height (e.g., increased spacing between adjacent vertebral

endplates), also marked by ovals Y. The lines X and the ovals Y are provided in FIGS. 9A-1-9B-2 to more clearly demonstrate the correction between the virtual models 910 and 920, and are not necessarily included on the virtual models generated in accordance with the present technology.

[0165] FIG. 10A illustrates an example of a surgical plan 1000. The surgical plan 1000 can include pre-operative patient metrics or measurements 1002, intra-operative patient metrics 1004, one or more patient images (e.g., the patient images 703 received as part of the patient data set), the virtual model 910 (which can be the model itself or one or more images derived from the model) of the patient's native anatomical configuration (e.g., pre-operative patient anatomy), and/or the intra-operative or post-operative virtual model 920 (which can be the model itself or one or more images derived from the model) of the patient's corrected anatomical configuration (e.g., intra-operative patient anatomy). The illustrated virtual model 920 is an intra-operative model. In some embodiments, the surgical plan 1000 can include one or more pre-operative models, intra-operative models, post-operative models, disease progression models, and/or other models. The models, or images of the models, can be displayed to provide pathological information for pre-operative planning and evaluation, developing surgical steps (e.g., planning pre-operative steps, assessing intra-operative steps, etc.), and planning post-operative outcomes. The surgical plan 1000 can include metrics. Pre-operative patient metrics 1002 can include, without limitation, lumbar lordosis, Cobb angle(s), pelvic incidence, disc height, coronal offset distance, segment flexibility, LL-PI is greater than predetermined degrees (e.g., 5 degrees, 10 degrees, etc.), LL-PI mismatch (e.g., age-adjusted), sagittal vertical axis offset distance, coronal offset distance, coronal angle, bone quality, rotational displacement. Different metrics can be generated for models of hips, knees, jaws, hands, shoulders, elbows, skulls, feet, ankles, organs, vascular features, etc.

[0166] The metrics can be selected by healthcare provider or automated selection system to provide metrics suitable for evaluating the procedure to be performed. For example, a hip replacement surgery can include metrics related to predicted post-operative pain, body posture, hip movement, or the like. A knee surgery procedure can include metrics related to, for example, range of motion, anatomical position of joint features, or the like. In some embodiments, metrics can be selected based on the user. For example, anatomical metrics, surgical steps, and other procedure-related metrics can

be provided to a healthcare provider. Patient metrics can include, for example, general range of motion, images of range of motion, predicted recovery times, or the like. This allows a set of metrics to be provided to the user to assist with user review. For reimbursements in billing, post-operative and pre-operative metrics can be provided for evaluating qualification for reimbursement.

[0167] The virtual model 920 of the intra-operative or post-operative patient anatomy can optionally include one or more implants 1012 shown as implanted in the patient's spinal region to show post-operative outcomes. Although four implants 1012 are shown in the virtual model 920, the surgical plan 1000 may include more or fewer implants 1012, including one, two, three, five, six, seven, eight, or more implants 1012. The computing system (e.g., computing system 100) can update the virtual model 920 and implant design for the implants 1012 based on collected patient data. For example, as a patient gains weight, loses weight, exercises, rehabilitates, progresses during a disease, recovers from injuries, or any activity, the virtual model 920 and implant designs can change to accurately represent the current patient anatomy and the correction needed. The computing system can update the virtual model 920 and implant design based on image data (e.g., x-ray images, CT scans, MRI scans, etc) that is collected during pre-operative, intra-operative, and post-operative procedures of a patient.

[0168] The surgical plan 1000 can include additional information beyond what is illustrated in FIG. 10A. For example, the surgical plan 1000 may include pre-operative instructions, operative instructions, and/or post-operative instructions. Operative instructions can include one or more specific procedures to be performed (e.g., PLIF, ALIF, TLIF, LLIF, DLIF, XLIF, etc.) and/or one or more specific targets of the operation (e.g., fusion of vertebral levels L1-L4, anchoring screw to be inserted in lateral surface of L4, etc.). Although the surgical plan 1000 is demonstrated in FIG. 10A as a visual report, the surgical plan 1000 can also be encoded in computer-executable instructions that, when executed by a processor connected to a computing device, cause the surgical plan 1000 to be displayed by the computing device. In some embodiments, the surgical plan 1000 may also include machine-readable operative instructions for carrying out the surgical plan. For example, the surgical plan can include operative instructions for a robotic surgical platform to carry out one or more steps of the surgical plan 1000.

[0169] The computing systems can provide interactive interfaces or displays for coordinating viewing, modification, and/or approval of the surgical plan, planned pathology, metrics, etc. The illustrated surgical plan 1000 can be displayed via an interactive interface. A user can view, approve, modify, or reject features of the surgical plan. For example, healthcare providers can change intra-operative or postoperative data (e.g., planned or predicted data) to generate new intra-operative or postoperative models for review. The system can automatically generate new anatomical metrics displayed to the user. For example, the healthcare provider can adjust the lordosis angle of L2/3. The system can update the lordosis angles of one or more of L3-4, L4-5, and/or L5/S1 based on dependency relationships between anatomical features. Accordingly, the system can generate updated metrics for the illustrated anatomy. Advantageously, multiple users (e.g., a patient, physician, etc.) can concurrently view the surgical plan 1000 in real time or near real time. This allows the physician to discuss potential treatments using a telehealth system.

[0170] A physician may modify the surgical plan 1000 and review and approve the modified surgical plan (e.g., planned or predicted post-operative pathology) prior to allowing viewing by the patient. This allows a healthcare provider to develop surgical plans prior to patient review. The surgical plan 1000 for patient review can include a limited amount of modifiable or viewable data. This allows the patients to review data most relevant or understandable by the patient. A user (e.g., a patient or related family member) may not be able to modify the metrics modifiable by the healthcare provider. In some embodiments, the user can select features of the models for tagging, adding questions, or inputting remarks. This allows a user to provide input on a surgical plan 1000 while maintaining the integrity of the surgical plan. The healthcare provider can then review the patient input in near real time or real time. In some implementations, the system can store multiple surgical plans 1000. Each surgical plan can be tailored or designed for particular users. The surgical plans can be associated with each other to provided synchronization of data. This allows propagation of surgical plan modifications, or other modifications, to other linked surgical plans or accounts. For example, if a manufacturer modifies an implant design, the impact of that modification can be included in linked surgical plans or accounts for physician, patient, and/or third-party review. The propagation rules can be based on levels of user access. For example, if a user with a low level of authorization makes a modification, that modification can be prohibited from

being made to accounts with higher levels of authorization. If a user with a high level of authorization makes a modification, that modification can be made to accounts with higher levels of authorization. A user can set a control list or propagation rule setting(s) based on authorization levels. The interface can include, without limitation, synchronization settings, list of linked surgical plans, selectable items (e.g., metrics tables, anatomical elements in models, virtual models, etc.), selection menus, drop down lists, and other selectable features for managing input, such as user feedback, image data (e.g., how to upload data, such as images), studies (e.g., image studies), etc.

[0171] FIG. 10B illustrates an exemplary interactive user interface 1050 of a surgical plan review program to access patient healthcare data, according to an embodiment. A user (e.g., patient, healthcare provider, etc.) can access viewable versions of the healthcare data for the patient via user interface 1050. For example, the user interface 1050 displays graphs to illustrate a patient's health metrics, display a surgical plan, virtual mode or provide the patient with medical images, such as x-ray images, CT scans, MRI scans, etc.

[0172] The selectable features of the user interface 1050 can be selected based on user settings, status of user, or the like. The user settings can be inputted by the user to provide a customizable user interface 1050 for managing available data. The user status can be, for example, patient, healthcare provider, insurance company, implant designer, implant manufacturer, or the like. For example, the displayed user interface 1050 of 10B can be displayed to patients and healthcare providers. The user interface 1050 can be modified to remove the digital wallet or insurance information for viewing by an implant manufacturer. The configuration and displayed information of the interactive user interface 1050 can be selected based on other criteria.

[0173] FIG. 11 provides a series of images illustrating an example of a patient surgical plan report 1100 that includes the surgical plan 1000 and that may be transmitted to a surgeon for review and approval (e.g., as transmitted in step 508 of the method 500). The surgical plan report 1100 can include a multi-page report detailing aspects of the surgical plan 1000. For example, the multi-page report may include a first page 1101 demonstrating an overview of the surgical plan 1000 (e.g., as shown in FIG. 10A), a second page 1102 illustrating patient images (e.g., such as the patient images 703 received in step 506), a third page 1103 illustrating an enlarged view of the virtual model

of the corrected anatomical configuration (e.g., the virtual model 920 shown in FIGS. 9B-1 and 9B-2), and a fourth page 1104 prompting the surgeon to either approve or reject the surgical plan via a user input element 901 (e.g., one or more buttons, a drop down menu, etc.). The surgical plan report 1100 can include one or more pre-operative metrics for pre-determined indications.

[0174] Page two 1102 can include pre-operative metrics 1109 determined based on the patient images 1103. The pre-operative metrics 1109 can be used to perform a reimbursement analysis, including whether a procedure, kit, instrument, implants, or other treatment-related item or step will qualify for payment or reimbursement. In some embodiments, planned metrics 1118 (page 1101) can be used to validate a predicted outcome for the pre-determined indications will qualify for payment or reimbursement.

[0175] Page two 1102 can also include reimbursement data 123 and regulatory data 127. The reimbursement data 123 can include the data discussed in connection with FIG. 10B. The output (e.g., recommended codes) can be labeled in the illustrated images 703. The pre-operative metrics 1109 correlated to the coding can be bolded or otherwise identified. This allows a user to simultaneously view reimbursement information and pathology/treatments/etc. associated with those reimbursements. The regulatory data 127 can include images of virtual models with anatomical features and regulatory compliant implants. The planned anatomical model (e.g., virtual anatomical model 920 of FIG. 10A) can have implants with regulatory approved configurations. The physician can therefore have confidence that the implants and planned outcome is based on regulatory approved technology.

[0176] In some embodiments, the system can measure the anatomical features and generate virtual models. The system can then generate the regulatory compliant implants that fit the model. If the physician modifies the model or implants resulting in a non-regulatory compliant treatment or implant, the system can generate an alert indicating that regulatory compliance has not been maintained. Advantageously, page 1102 allows a user to simultaneously view patient images, anatomical planned models, planned pathologies based on regulatory compliance, reimbursement data, and regulatory data. Moreover, correlations between various elements of different data sets can be identified to enable a viewer to understand the interrelationships.

[0177] Of course, additional information about the surgical plan can be presented with the report 1100 in the same or different formats. In some embodiments, if the surgeon rejects the surgical plan 1000, the surgeon can be prompted to provide feedback regarding aspects of the surgical plan 1000 the surgeon would like adjusted.

[0178] The patient surgical plan report 1100 can be presented to the surgeon on a digital display of a computing device (e.g., the client computing device 102 shown in FIG. 1). In some embodiments, the report 1100 is interactive and the surgeon can manipulate various aspects of the report 1100 (e.g., adjust views of the virtual model, zoom-in, zoom-out, annotate, etc.). However, even if the report 1100 is interactive, the surgeon generally cannot directly change the surgical plan 1000. Rather, the surgeon may provide feedback and suggested changes to the surgical plan 1000, which can be sent back to the computing system that generated the surgical plan 1000 for analysis and refinement.

[0179] The patient surgical plan report 1100 can be viewed by additional users. For example, a patient or implant manufacturer can access and review the plan report 1100 using the system disclosed herein. In another example, the patient may want to simultaneously view reimbursement information and physiological information associated with his reimbursements using page 1102 of the report.

[0180] In some embodiments, the patient surgical plan report 1100 can be designed based on the authentication level of the user. The system can receive a user request to access the patient surgical plan report 1100 and determine an authentication level for the. A system can determine, based on the authentication level of the user, an amount of patient-specific healthcare data to include in the patient surgical plan report 1100. The system can then generate and transmit the patient surgical plan report 1100. The system can also determine whether any linked accounts or users are authorized for receiving the patient surgical plan report 1100. For example, the patient surgical plan report 1100 can be transmitted to multiple linked accounts associated with family members of the patient. This allows users with the same authorization level to receive matching (or identical) patient surgical plan reports 1100. The patient surgical plan report 1100 can include selectable features (e.g., models, metrics, surgical steps, planned outcomes, predictions, etc.) for rejection, approval, and/or modification. The available selectable features can be selected based on, for example, the authentication level of the user, user status, etc. Accordingly, the authentication level can be used to select/coordinate the selectable

features, amount of healthcare data available to the user, available input/feedback provided by the user, or combinations thereof.

[0181] FIG. 12A illustrates an example of a patient-specific implant 1200 (e.g., as designed in step 516 and manufactured in step 518 of the method 500), and FIG. 12B illustrates the implant 1200 implanted in the patient. The implant 1200 can be any orthopedic or other implant specifically designed to induce the patient's body to conform to the previously identified corrected anatomical configuration. The implant 1202 can be based on a design generated by mapping a negative space between segmented anatomic elements of a corrected pathology. The negative space is then filled with a virtual implant. In imbursement-constrained embodiments, the configuration of the negative space can be selected based on one or more parameters for the medical reimbursable virtual implant. For example, the implant 1200 can be a cervical fusion implant, a lumbar fusion implant, an artificial disc, an expandable intervertebral cage, or other implant disclosed herein.

[0182] For example, system 100 of FIG. 1 can obtaining insurance information for the patient from the database 110. The system 100 can then retrieve one or more design parameters from a database 110 based on the obtained insurance information. The treatment model can then design the patient-specific implant 1202 using the retrieved design parameter(s). The design parameters can be a configuration (e.g., an implant footprint shown in dashed line in FIG. 12A) for devices approved for use by regulatory agency or governmental body, payment requirement, imbursement requirement, etc. Prior to manufacturing the implant 1202, the system can notify the user of the at least one medical reimbursement code for user review and approval.

[0183] In the illustrated embodiment, the implant 1200 is a vertebral interbody device having a first (e.g., upper) surface 1202 configured to engage an inferior endplate surface of a superior vertebral body and a second (e.g., lower) surface 1204 configured to engage a superior endplate surface of an inferior vertebral body. The first surface 1202 can have a patient-specific topography designed to match (e.g., mate with) the topography of the inferior endplate surface of the superior vertebral body to form a generally gapless interface therebetween. Likewise, the second surface 1204 can have a patient-specific topography designed to match or mate with the topography of the superior endplate surface of the inferior vertebral body to form a generally gapless

interface therebetween. The implant 1200 may also include a recess 1206 or other features configured to promote bony ingrowth. Because the implant 1200 is patient-specific and designed to induce a geometric change in the patient, the implant 1200 is not necessarily symmetric, and is often asymmetric. For example, in the illustrated embodiment, the implant 1200 has a non-uniform thickness such that a plane defined by the first surface 1202 is not parallel to a central longitudinal axis A of the implant 1200. Of course, because the implants described herein, including the implant 1200, are patient-specific, the present technology is not limited to any particular implant design or characteristic. Additional features of patient-specific implants that can be designed and manufactured in accordance with the present technology are described in U.S. Patent Application Nos. 16/987,113 and 17/100,396, the disclosures of which are incorporated by reference herein in their entireties.

[0184] The patient-specific medical procedures described herein can involve implanting more than one patient-specific implant into the patient to achieve the corrected anatomical configuration (e.g., a multi-site procedure). FIG. 13, for example, illustrates a lower spinal cord region having three patient specific implants 1300a-1300c implanted at different vertebral levels. More specifically, a first implant 1300a is implanted between the L3 and L4 vertebral bodies, a second implant 1300b is implanted between the L4 and L5 vertebral bodies, and a third implant 1300c is implanted between the L5 vertebral body and the sacrum. Together, the implants 1300a-c can cause the patient's spinal cord region to assume the previously identified corrected anatomical configuration (e.g., transforming the patient's anatomy from its pre-operative diseased configuration to the post-operative optimized configuration). In some embodiments, more or fewer implants are used to achieve the corrected anatomical configuration. For example, in some embodiments one, two, four, five, six, seven, eight, or more implants are used to achieve the corrected anatomical configuration. In embodiments involving more than one implant, the implants do not necessarily have the same shape, size, or function. In fact, the multiple implants will often have different geometries and topographies to correspond to the target vertebral level at which they will be implanted. As also shown in FIG. 13, the patient-specific medical procedures described herein can involve treating the patient at multiple target regions (e.g., multiple vertebral levels).

[0185] In addition to designing patient-specific medical care based on reference patient data sets, the systems and methods of the present technology may also design

patient-specific medical care based on disease progression for a particular patient. In some embodiments, the present technology therefore includes software modules (e.g., machine learning models or other algorithms) that can be used to analyze, predict, and/or model disease progression for a particular patient. The machine learning models can be trained based on a plurality of reference patient data sets that includes, in addition to the patient data described with respect to FIG. 1, disease progression metrics for each of the reference patients. The progression metrics can include measurements for disease metrics over a period of time. Suitable metrics may include spinopelvic parameters (e.g., lumbar lordosis, pelvic tilt, sagittal vertical axis (SVA), Cobb angle, coronal offset, etc.), disability scores, functional ability scores, flexibility scores, VAS pain scores, or the like. The progression of the metrics for each reference patient can be correlated to other patient information for the specific reference patient (e.g., age, sex, height, weight, activity level, diet, etc.).

[0186] In some embodiments, the present technology includes a disease progression module that includes an algorithm, machine learning model, or other software analytical tool for predicting disease progression in a particular patient. The disease progression module can be trained based on reference patient data sets that includes patient information (e.g., age, sex, height, weight, activity level, diet) and disease metrics (e.g., diagnosis, spinopelvic parameters such as lumbar lordosis, pelvic tilt, sagittal vertical axis, cobb angel, coronal offset, etc., disability scores, functional ability scores, flexibility scores, VAS pain scores, etc.). The disease metrics can include values over a period of time. For example, the reference patient data may include values of disease metrics on a daily, weekly, monthly, bi-monthly, yearly, or other basis. By measuring the metrics over a period of time, changes in the values of the metrics can be tracked as an estimate of disease progression and correlated to other patient data.

[0187] In some embodiments, the disease progression module can therefore estimate the rate of disease progression for a particular patient. The progression may be estimated by providing estimated changes in one or more disease metrics over a period of time (e.g., X% increase in a disease metric per year). The rate can be constant (e.g., 5% increase in pelvic tilt per year) or variable (e.g., 5% increase in pelvic tilt for a first year, 10% increase in pelvic tilt for a second year, etc.). In some embodiments, the estimated rate of progression can be transmitted to a surgeon or other healthcare provider, who can review and update the estimate, if necessary.

[0188] As a non-limiting example, a particular patient who is a fifty-five-year-old male may have a SVA value of 6mm. The disease progression module can analyze patient reference data sets to identify disease progression for individual reference patients have one or more similarities with the particular patient (e.g., individual patients of the reference patients who have an SVA value of about 6 mm and are approximately the same age, weight, height, and/or sex of the patient). Based on this analysis, the disease progression module can predict the rate of disease progression if no surgical intervention occurs (e.g., the patient's VAS pain scores may increase 5%, 10%, or 15% annually if no surgical intervention occurs, the SVA value may continue to increase by 5% annually if no surgical intervention occurs, etc.).

[0189] The systems and methods described herein can also generate models/simulations based on the estimated rates of disease progression, thereby modeling different outcomes over a desired period of times. Additionally, the models/simulations can account for any number of additional diseases or conditions to predict the patient's overall health, mobility, or the like. These additional diseases or conditions can, in combination with other patient health factors (e.g., height, weight, age, activity level, etc.) be used to generate a patient health score reflecting the overall health of the patient. The patient health score can be displayed for surgeon review and/or incorporated into the estimation of disease progression. Accordingly, the present technology can generate one or more virtual simulations of the predicted disease progression to demonstrate how the patient's anatomy is predicted to change over time. Physician input can be used to generate or modify the virtual simulation(s). The present technology can generate one or more post-treatment virtual simulations based on the received physician input for review by the healthcare provider, patient, etc.

[0190] In some embodiments, the present technology can also predict, model, and/or simulate disease progression based on one or more potential surgical interventions. For example, the disease progression module may simulate what a patient's anatomy may look like 1, 2, 5, or 10 years post-surgery for several surgical intervention options. The simulations may also incorporate non-surgical factors, such as patient age, height, weight, sex, activity level, other health conditions, or the like, as previously described. Based on these simulations, the system and/or a surgeon can select which surgical intervention is best suited for long-term efficacy. These simulations

can also be used to determine patient-specific corrections that compensate for the projected diseases progression.

[0191] Accordingly, in some embodiments, multiple disease progression models (e.g., two, three, four, five, six, or more) are simulated to provide disease progression data for several different surgical intervention options or other scenarios. For example, the disease progression module can generate models that predict post-surgical disease progression for each of three different surgical interventions. A surgeon or other healthcare provider can review the disease progression models and, based on the review, select which of the three surgical intervention options is likely to provide the patient with the best long-term outcome. Of course, selecting the optimal intervention can also be fully or semi-automated, as described herein.

[0192] Based off of the modeled disease progression, the systems and methods described herein can also (i) identify the optimal time for surgical intervention, and/or (ii) identify the optimal type of surgical procedure for the patient. In some embodiments, the present technology therefore includes an intervention timing module that includes an algorithm, machine learning model, or other software analytical tool for determining the optimal time for surgical intervention in a particular patient. This can be done, for example, by analyzing patient reference data that includes (i) pre-operative disease progression metrics for individual reference patients, (ii) disease metrics at the time of surgical intervention for individual reference patients, (iii) post-operative disease progression metrics for individual reference patients, and/or (iv) scored surgical outcomes for individual reference patients. The intervention timing module can compare the disease metrics for a particular patient to the reference patient data sets to determine, for similar patients, the point of disease progression at which surgical intervention produced the most favorable outcomes.

[0193] As a non-limiting example, the reference patient data sets may include data associated with reference patients' sagittal vertical axis. The data can include (i) sagittal vertical axis values for individual patients over a period of time before surgical intervention (e.g., how fast and to what degree the sagittal vertical axis value changed), (ii) sagittal vertical axis of the individual patients at the time of surgical intervention, (iii) the change in sagittal vertical axis after surgical intervention, and (iv) the degree to which the surgical intervention was successful (e.g., based on pain, quality of life, or other

factors). Based on the foregoing data, the intervention timing module can, based on a particular patient's sagittal vertical axis value, identify at which point surgical intervention will have the highest likelihood of producing the most favorable outcome. Of course, the foregoing metric is provided by way of example only, and the intervention timing module can incorporate other metrics (e.g., lumbar lordosis, pelvic tilt, sagittal vertical axis, cobb angle, coronal offset, disability scores, functional ability scores, flexibility scores, VAS pain scores) instead of or in combination with sagittal vertical axis to predict the time at which surgical intervention has the highest probability of providing a favorable outcome for the particular patient.

[0194] The intervention timing module may also incorporate one or more mathematical rules based on value thresholds for various disease metrics. For example, the intervention timing module may indicate surgical intervention is necessary if one or more disease metrics exceed a predetermined threshold or meet some other criteria. Representative thresholds that indicate surgical intervention may be necessary and can include SVA values greater than 7mm, a mismatch between lumbar lordosis and pelvic incidence greater than 10 degrees, a Cobb angle of greater than 10 degrees, and/or a combination of Cobb angle and LL/PI mismatch greater than 20 degrees. Of course, other threshold values and metrics can be used; the foregoing are provided as examples only and in no way limit the present disclosure. In some embodiments, the foregoing rules can be tailored to specific patient populations (e.g., for males over 50 years of age, an SVA value greater than 7mm indicates the need for surgical intervention). If a particular patient does not exceed the thresholds indicating surgical intervention is recommended, the intervention timing module may provide an estimate for when the patient's metrics will exceed one or more thresholds, thereby providing the patient with an estimate of when surgical intervention may become recommended.

[0195] The present technology may also include a treatment planning module that can identify the optimal type of surgical procedure for the patient based on the disease progression of the patient. The treatment planning module can be an algorithm, machine learning model, or other software analytical tool trained or otherwise based on a plurality of reference patient data sets, as previously described. The treatment planning module may also incorporate one or more mathematical rules for identifying surgical procedures. As a non-limiting example, if a LL/PI mismatch is between 10 and 20 degrees, the treatment planning module may recommend an anterior fusion surgery, but if the LL/PI

mismatch is greater than 20 degrees, the treatment planning module may recommend both anterior and posterior fusion surgery. As another non-limiting example, if a SVA value is between 7mm and 15mm, the treatment planning module may recommend posterior fusion surgery, but if the SVA is above 15 mm, the treatment planning module may recommend both posterior fusion surgery and anterior fusion surgery. Of course, other rules can be used; the foregoing are provided as examples only and in no way limit the present disclosure.

[0196] Without being bound by theory, incorporating disease progression modeling into the patient-specific medical procedures described herein may even further increase the effectiveness of the procedures. For example, in many cases it may be disadvantageous to operate after a patient's disease progresses to an irreversible or unstable state. However, it may also be disadvantageous to operate too early, before the patient's disease is causing symptoms and/or if the patient's disease may not progress further. The disease progression module and/or the intervention timing module can therefore help identify the window of time during which surgical intervention in a particular patient has the highest probability of providing a favorable outcome for the patient.

[0197] As one skilled in the art will appreciate, any of the software modules described previously may be combined into a single software module for performing the operations described herein. Likewise, the software modules can be distributed across any combination of the computing systems and devices described herein, and are not limited to the express arrangements described herein. Accordingly, any of the operations described herein can be performed by any of the computing devices or systems described herein, unless expressly noted otherwise.

[0198] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In some embodiments, several portions of the subject matter described herein may be implemented via Application Specific

Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually in any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one skilled in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as a program product in a variety of forms, and that an illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a CD, a DVD, a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

Examples

[0199] The present technology is illustrated, for example, according to various aspects described below. Various examples of aspects of the present technology are described as numbered examples (1, 2, 3, etc.) for convenience. These are provided as examples and do not limit the present technology. It is noted that any of the dependent examples can be combined in any suitable manner, and placed into a respective independent example. The other examples can be presented in a similar manner.

1. A computer-implemented method for providing patient-specific healthcare data from an implant, the method comprising:
 - receiving the patient-specific healthcare data from at least one input data source;
 - storing the patient-specific healthcare data in a healthcare digital filing cabinet;
 - managing access to the patient-specific healthcare data based on one or more authentication levels;

receiving, by a user, a request to access the patient-specific healthcare data;
determining an authentication level associated with the user;
determining, based on the authentication level, an amount of the patient-specific healthcare data to provide to the user; and
transmitting, to a user interface of the user, the determined amount of the patient-specific healthcare data.

2. The computer-implemented method of example 1, further comprising:
identifying one or more linked accounts from at least one entity related to the patient-specific healthcare data and the implant;
determining whether the identified one or more linked accounts are authorized for receiving the patient-specific healthcare data; and
in response to determining that the one or more linked accounts are authorized, transmitting the patient-specific healthcare data to the at least one entity.

3. The computer-implemented method of examples 1-2, further comprising:
receiving data sharing rules from a patient owner of the healthcare digital filing cabinet; and
automatically transmitting the determined amount of the patient-specific healthcare data according to the received data sharing rules.

4. The computer-implemented method of examples 1-3, wherein the data sharing rules include at least one of a physician sharing rule, a hospital sharing rule, or an implant manufacture sharing rule.

5. The computer-implemented method of examples 1-4, wherein the data sharing rules include at least one a patient identifier setting, a data type sharing rule, or a meta data setting.

6. The computer-implemented method of examples 1-5, further comprising:
determining whether the patient-specific healthcare data is associated with the implant; and

in response to determining that the patient-specific healthcare data is associated with the implant, transmitting at least a portion for the patient-specific healthcare data for a physician managing treatment involving the implant.

7. The computer-implemented method of examples 1-6, wherein the patient-specific healthcare data includes one or more scans of the patient.

8. The computer-implemented method of examples 1-7, further comprising: linking accounts from multiple entities related to the patient-specific healthcare data into the healthcare digital filing cabinet.

9. The computer-implemented method of examples 1-8, further comprising: encrypting the patient-specific healthcare data prior to transmission.

10. The computer-implemented method of examples 1-9, further comprising: integrating input data sources of the implant for the patient-specific healthcare data.

11. The computer-implemented method of examples 1-10, wherein the authentication level requires a two-factor authentication.

12. The computer-implemented method of examples 1-11, wherein the authentication level of the user is based on a geolocation, biometric data, or authentication credentials.

13. The computer-implemented method of examples 1-14, wherein the implant is a blockchain-enabled medical implant that is implanted in a body of a patient, the method further comprising:

establishing a communicative contact using a proximity communication mode; and accessing, based on the authentication level, a private key stored on the blockchain-enabled medical implant to access the patient-specific healthcare data in the healthcare digital filing cabinet.

14. The computer-implemented method of examples 1-13, wherein the user is a healthcare provider or a patient.

15. The computer-implemented method of examples 1-14, wherein the patient-specific healthcare data is locked such that the user cannot initially access the data, the method further comprising:

- receiving authentication information from the user;
- authenticating the user based on the received authentication information; and
- in response to authenticating the user, unlocking a portion of the patient-specific healthcare data.

16. The computer-implemented method of examples 1-15, wherein the authentication information indicates the authentication level.

17. The computer-implemented method of examples 1-16, further comprising:

- receiving authentication information;
- determining the authentication information is not valid; and
- in response to determining the authentication information is not valid, locking the healthcare digital filing cabinet.

18. The computer-implemented method of examples 1-17, further comprising notifying the user of locking of the healthcare digital filing cabinet.

19. A computer-implemented method for analyzing patient-specific healthcare data, the method comprising:

- analyzing patient-specific healthcare data collected from at least one wearable device and a healthcare digital filing cabinet associated with an implant;
- identifying at least one patient healthcare goal based on the patient-specific healthcare data, wherein the at least one patient healthcare goal is provided by at least one of the patient or at least one healthcare provider of the patient;

determining at least one health metric collected by the at least one wearable device is not within a health range of the at least one patient healthcare goal; and
generating a notification to alert the patient of the at least one health metric.

20. The computer-implemented method of example 19, further comprising:
receiving post-operative healthcare data from the at least one healthcare provider;
and
updating the patient-specific healthcare data with the post-operative healthcare data.

21. The computer-implemented method of examples 19-20, further comprising:
identifying a manufacturer of the implant has an update or a recall for the implant;
and
generating a second notification to alert the patient of the update or the recall by the manufacturer for the implant.

22. The computer-implemented method of examples 19-21, further comprising:
identifying an insurance claim associated with the patient in the patient-specific healthcare data; and
scrapping information from the insurance claim that requires action by the patient.

23. The computer-implemented method of examples 19-22, further comprising:
displaying, on user interface, images of the patient-specific healthcare data.

24. The computer-implemented method of examples 19-23, further comprising:
comparing a patient healthcare goal provided by the patient with a patient healthcare goals provided by the at least one healthcare provider of the patient; and
identifying differences between the patient healthcare goal provided by the patient and the patient healthcare goals provided by the at least one healthcare provider.

25. The computer-implemented method of examples 19-24, wherein the notification includes physical therapy instructions, diet instructions, exercise instructions, or the at least one health metric.

26. The computer-implemented method of examples 19-25, further comprising: identifying an adverse event based on the patient-specific healthcare data; and in response to the identification, sending a notification alerting the at least one of the patient or the at least one healthcare provider of the adverse event.

27. The computer-implemented method of examples 19-26, wherein the adverse event includes misalignment of the patient's spine that exceeds an acceptable alignment parameter.

28. A computer-implemented method for managing patient-specific healthcare data by a healthcare provider, the method comprising:

linking to a patient-managed account storing patient data associated with a patient-specific implant;
receiving patient data from the patient-managed account;
analyzing the received patient data to identify a relevant training parameter;
generating a reference data set with the received patient data based on the relevant training parameter; and
training one or more machine learning models based at least in part on the reference data set for designing implants similar to the patient-specific implant.

29. The computer-implemented method of example 28, wherein the relevant training parameter is a categorized spinal condition, wherein the categorization is based on one or more predetermined thresholds.

30. The computer-implemented method of examples 28-29, wherein the predetermined thresholds include a threshold level-specific lumbar lordosis, a threshold Cobb angle, a threshold pelvic incidence, and/or a threshold disc height.

31. The computer-implemented method of examples 28-30, wherein analyzing the received patient data includes at least one of
comparing the received patient data to preoperative data of the patient; or
identifying at least a portion of the patient data for the reference data set based on the comparison.
32. The computer-implemented method of examples 28-31, further comprising:
determining an outcome score for the patient based on the received patient data;
in response to the outcome score exceeding a threshold score, associating the patient data with one or more spinal conditionals in which the one or more machine learning models are configured to generate patient-specific surgical plans.
33. The computer-implemented method of examples 28-32, further comprising:
analyzing the received patient data to determine whether the patient data meets one or criteria for training the one or more machine learning models.
34. The computer-implemented method of examples 28-33, wherein determining whether the patient data meets one or criteria includes is based on resolution of one or more patient images of the received patient data.
35. The computer-implemented method of examples 28-34, further comprising:
automatically modifying the one or more machine learning models in response to receipt of additional patient data.
36. The computer-implemented method of examples 28-35, wherein the patient-managed account includes a patient digital filing cabinet created by the healthcare provider.
37. The computer-implemented method of examples 28-36, further comprising linking to the patient-managed account using encoded data from one or more patient scans in the received patient data.

38. A computer-implemented method for managing patient-specific healthcare data by a healthcare provider, the method comprising:
- integrating patient-specific healthcare data from a digital filing cabinet into healthcare provider managed analytics;
 - managing the patient-specific healthcare data by:
 - collecting health metrics of a patient from at least one wearable device,
 - generating patient health goals based on the patient-specific healthcare data, and
 - determining privacy settings to access the patient-specific healthcare data, and
 - generating, based on the privacy settings, a version of the patient-specific healthcare data to display on a user interface.
39. The computer-implemented method of example 38, further comprising:
- performing post-operative analytics on post-operative healthcare data; and
 - updating the patient-specific healthcare data based on the post-operative analytics.
40. The computer-implemented method of examples 38-39, further comprising:
- transmitting the patient-specific healthcare data to an implant of the patient.
41. The computer-implemented method of examples 38-40, further comprising:
- receiving the patient-specific healthcare data from an implant of the patient.
42. The computer-implemented method of examples 38-41, further comprising:
- identifying healthcare provider data; and
 - integrating the healthcare provider data into the healthcare provider managed analytics.
43. The computer-implemented method of examples 38-42, further comprising:
- identifying changes to a health insurance plan of the patient; and
 - applying the changes to the patient-specific healthcare data.

44. The computer-implemented method of examples 38-43, wherein the patient-specific healthcare data includes surgical procedures, health history data of the patient, or health insurance information.
45. A computing system comprising:
one or more processors; and
one or more memories storing instructions that, when executed by the one or more processors, cause the computing system to perform a process of any one of methods in examples 1-44.
46. A non-transitory computer-readable medium storing instructions that, when executed by a computing system, cause the computing system to perform operations of any one of methods in examples 1-44.
47. A computer-implemented method for providing patient-specific healthcare data from an implant, the method comprising:
establishing a communicative contact with a patient-specific medical implant implanted in a body of a patient by a device associated with a user using a proximity communication mode,
wherein the patient-specific medical implant contains patient-specific healthcare data;
receiving, by the user, a request to access the patient-specific healthcare data in the patient-specific medical implant;
determining, based on an authentication level associated with the user, an amount of the patient-specific healthcare data to provide to the user; and
transmitting, to the device of the user from the patient-specific medical implant, the determined amount of the patient-specific healthcare data.
48. A computing system comprising:
one or more processors; and
one or more memories storing instructions that, when executed by the one or more processors, cause the computing system to perform a process of the method in example 47.

49. A non-transitory computer-readable medium storing instructions that, when executed by a computing system, cause the computing system to perform operations of the method in example 47.

50. A computer-implemented method for providing patient-specific healthcare data associated with a patient-specific medical implant, the method comprising:

receiving the patient-specific healthcare data of a patient from at least one input data source;

generating, based on the patient-specific healthcare data, a patient-specific interactive surgical plan for implanting the patient-specific medical implant in a body of the patient;

receiving, from a user, a request to modify the patient-specific interactive surgical plan;

determining, based on an authentication level of the user, whether the user is authorized to modify the patient-specific interactive surgical plan;

in response to determining the user is authorized to modify the patient-specific interactive surgical plan, displaying, via a user-interface, the patient-specific interactive surgical plan;

detecting a modification to the patient-specific interactive surgical plan by the user;

modifying the patient-specific interactive surgical plan based on the modification of the surgical plan by the user, wherein a design and placement of the patient-specific medical implant is modified; and

storing the modified patient-specific interactive surgical plan in a healthcare digital filing cabinet.

51. A computing system comprising:

one or more processors; and

one or more memories storing instructions that, when executed by the one or more processors, cause the computing system to perform a process of the method in example 50.

52. A non-transitory computer-readable medium storing instructions that, when executed by a computing system, cause the computing system to perform operations of the method in example 50.

[0200] As one skilled in the art will appreciate, any of the software modules described previously may be combined into a single software module for performing the operations described herein. Likewise, the software modules can be distributed across any combination of the computing systems and devices described herein, and are not limited to the express arrangements described herein. Accordingly, any of the operations described herein can be performed by any of the computing devices or systems described herein, unless expressly noted otherwise.

[0201] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In some embodiments, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as a program product in a variety of forms, and that an illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as

a floppy disk, a hard disk drive, a CD, a DVD, a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

[0202] Those skilled in the art will recognize that it is common within the art to describe devices and/or processes in the fashion set forth herein, and thereafter use engineering practices to integrate such described devices and/or processes into data processing systems. That is, at least a portion of the devices and/or processes described herein can be integrated into a data processing system via a reasonable amount of experimentation. Those having skill in the art will recognize that a typical data processing system generally includes one or more of a system unit housing, a video display device, a memory such as volatile and non-volatile memory, processors such as microprocessors and digital signal processors, computational entities such as operating systems, drivers, graphical user interfaces, and applications programs, one or more interaction devices, such as a touch pad or screen, and/or control systems including feedback loops and control motors (e.g., feedback for sensing position and/or velocity; control motors for moving and/or adjusting components and/or quantities). A typical data processing system may be implemented utilizing any suitable commercially available components, such as those typically found in data computing/communication and/or network computing/communication systems.

[0203] The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively “associated” such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as “associated with” each other such that the desired functionality is achieved, irrespective of architectures or intermediate components. Likewise, any two components so associated can also be viewed as being “operably connected,” or “operably coupled,” to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being “operably couplable” to each other to achieve the desired functionality. Specific examples of operably couplable include but are not

limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0204] The embodiments, features, systems, devices, materials, methods and techniques described herein may, in some embodiments, be similar to any one or more of the embodiments, features, systems, devices, materials, methods and techniques described in the following:

U.S. Application No. 16/048,167, filed on July 27, 2017, titled “SYSTEMS AND METHODS FOR ASSISTING AND AUGMENTING SURGICAL PROCEDURES”;

U.S. Application No. 16/242,877, filed on January 8, 2019, titled “SYSTEMS AND METHODS OF ASSISTING A SURGEON WITH SCREW PLACEMENT DURING SPINAL SURGERY”;

U.S. Application No. 16/207,116, filed on December 1, 2018, titled “SYSTEMS AND METHODS FOR MULTI-PLANAR ORTHOPEDIC ALIGNMENT”;

U.S. Application No. 16/352,699, filed on March 13, 2019, titled “SYSTEMS AND METHODS FOR ORTHOPEDIC IMPLANT FIXATION”;

U.S. Application No. 16/383,215, filed on April 12, 2019, titled “SYSTEMS AND METHODS FOR ORTHOPEDIC IMPLANT FIXATION”;

U.S. Application No. 16/569,494, filed on September 12, 2019, titled “SYSTEMS AND METHODS FOR ORTHOPEDIC IMPLANTS”;

U.S. Application No. 62/773,127, filed on November 29, 2018, titled “SYSTEMS AND METHODS FOR ORTHOPEDIC IMPLANTS”;

U.S. Application No. 62/928,909, filed on October 31, 2019, titled “SYSTEMS AND METHODS FOR DESIGNING ORTHOPEDIC IMPLANTS BASED ON TISSUE CHARACTERISTICS”;

U.S. Application No. 16/735,222, filed January 6, 2020, titled "PATIENT-SPECIFIC MEDICAL PROCEDURES AND DEVICES, AND ASSOCIATED SYSTEMS AND METHODS";

U.S. Application No. 16/987,113, filed August 6, 2020, titled "PATIENT-SPECIFIC ARTIFICIAL DISCS, IMPLANTS AND ASSOCIATED SYSTEMS AND METHODS";

U.S. Application No. 16/990,810, filed August 11, 2020, titled "LINKING PATIENT-SPECIFIC MEDICAL DEVICES WITH PATIENT-SPECIFIC DATA, AND ASSOCIATED SYSTEMS, DEVICES, AND METHODS";

U.S. Application No.: 17/678,874, filed February 23, 2022, titled "NON-FUNGIBLE TOKEN SYSTEMS AND METHODS FOR STORING AND ACCESSING HEALTHCARE DATA";

U.S. Application No. 17/085,564, filed October 30, 2020, titles "SYSTEMS AND METHODS FOR DESIGNING ORTHOPEDIC IMPLANTS BASED ON TISSUE CHARACTERISTICS";

U.S. Application No. 17/100,396, filed November 20, 2020, titled "PATIENT-SPECIFIC VERTEBRAL IMPLANTS WITH POSITIONING FEATURES; "

U.S. Provisional Application No. 63/313,602, filed February 24, 2022, titled "SYSTEMS AND METHODS FOR STORING AND ACCESSING HEALTHCARE DATA IN DIGITAL FILING CABINET; "

U.S. Provisional Application No. 63/313,620, filed February 24, 2022, titled "SYSTEMS AND METHODS FOR ANALYZING PATIENT-SPECIFIC HEALTHCARE DATA;" and

U.S. Provisional Application No. 63/313,638, filed February 24, 2022, titled
“SYSTEMS AND METHODS FOR MANAGING PATIENT-SPECIFIC
HEALTHCARE DATA BY A HEALTHCARE PROVIDER.”

[0205] All of the above-identified patents and applications are incorporated by reference in their entireties. In addition, the embodiments, features, systems, devices, materials, methods and techniques described herein may, in certain embodiments, be applied to or used in connection with any one or more of the embodiments, features, systems, devices, or other matter. All patents and applications referenced herein are incorporated by reference in their entireties.

[0206] The ranges disclosed herein also encompass any and all overlap, sub-ranges, and combinations thereof. Language such as “up to,” “at least,” “greater than,” “less than,” “between,” or the like includes the number recited. Numbers preceded by a term such as “approximately,” “about,” and “substantially” as used herein include the recited numbers (e.g., about 10%=10%), and also represent an amount close to the stated amount that still performs a desired function or achieves a desired result. For example, the terms “approximately,” “about,” and “substantially” may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount.

[0207] From the foregoing, it will be appreciated that various embodiments of the present disclosure have been described herein for purposes of illustration, and that various modifications may be made without departing from the scope and spirit of the present disclosure. Accordingly, the various embodiments disclosed herein are not intended to be limiting.

CLAIMS

What is claimed is:

1. A system comprising:
one or more processors; and
one or more memories storing instructions that, when executed by the one or more processors, cause the system to perform a process providing patient-specific healthcare data from an implant, the process comprising:
establishing a communicative contact with a patient-specific medical implant implanted in a body of a patient by a device associated with a user using a proximity communication mode,
wherein the patient-specific medical implant contains patient-specific healthcare data;
receiving, by the user, a request to access the patient-specific healthcare data in the patient-specific medical implant;
determining, based on an authentication level associated with the user, an amount of the patient-specific healthcare data to provide to the user;
and
transmitting, to the device of the user from the patient-specific medical implant, the determined amount of the patient-specific healthcare data.
2. The system according to claim 1, wherein the process further comprises:
identifying one or more linked accounts from at least one entity related to the patient-specific healthcare data and the patient-specific medical implant;
determining whether the identified one or more linked accounts are authorized for receiving the patient-specific healthcare data; and
in response to determining that the one or more linked accounts are authorized, transmitting the patient-specific healthcare data to the at least one entity.
3. The system according to claim 1, wherein the process further comprises:
receiving the patient-specific healthcare data from at least one input data source;

storing the patient-specific healthcare data in a healthcare digital filing cabinet;
receiving data sharing rules from a patient owner of the healthcare digital filing cabinet; and

automatically transmitting the determined amount of the patient-specific healthcare data according to the received data sharing rules, wherein the data sharing rules include at least one of a physician sharing rule, a hospital sharing rule, or an implant manufacture sharing rule, wherein the data sharing rules include at least one a patient identifier setting, a data type sharing rule, or a meta data setting.

4. The system according to claim 1, wherein the process further comprises:
determining whether the patient-specific healthcare data is associated with the patient-specific medical implant; and

in response to determining that the patient-specific healthcare data is associated with the patient-specific medical implant, transmitting at least a portion for the patient-specific healthcare data for a physician managing treatment involving the patient-specific medical implant, wherein the patient-specific healthcare data includes one or more scans of the patient.

5. The system according to claim 1, wherein the process further comprises:
storing the patient-specific healthcare data in a healthcare digital filing cabinet;
linking accounts from multiple entities related to the patient-specific healthcare data into the healthcare digital filing cabinet.

6. The system according to claim 1, wherein the process further comprises:
encrypting the patient-specific healthcare data prior to transmission.

7. The system according to claim 1, wherein the process further comprises:
integrating input data sources of the patient-specific medical implant for the patient-specific healthcare data.

8. The system according to claim 1, wherein the patient-specific medical implant is a blockchain-enabled medical implant that is implanted in the body of a patient, wherein the process further comprises:

establishing the communicative contact using the proximity communication mode;
and
accessing, based on the authentication level, a private key stored on the blockchain-enabled medical implant to access the patient-specific healthcare data in a healthcare digital filing cabinet.

9. The system according to claim 1, wherein the patient-specific healthcare data is locked such that the user cannot initially access the patient-specific healthcare data, wherein the process further comprises:

receiving authentication information from the user;
authenticating the user based on the received authentication information; and
in response to authenticating the user, unlocking a portion of the patient-specific healthcare data.

10. The system according to claim 1, wherein the process further comprises:
notifying the user of locking of a healthcare digital filing cabinet that contains the patient-specific healthcare data.

11. A non-transitory computer-readable medium storing instructions that, when executed by a computing system, cause the computing system to perform operations for providing patient-specific healthcare data from an implant, the operations comprising:

establishing a communicative contact with a patient-specific medical implant implanted in a body of a patient by a device associated with a user using a proximity communication mode,
wherein the patient-specific medical implant contains patient-specific healthcare data;
receiving, by the user, a request to access the patient-specific healthcare data in the patient-specific medical implant;
determining, based on an authentication level associated with the user, an amount of the patient-specific healthcare data to provide to the user; and

transmitting, to the device of the user from the patient-specific medical implant, the determined amount of the patient-specific healthcare data.

12. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

identifying one or more linked accounts from at least one entity related to the patient-specific healthcare data and the patient-specific medical implant; determining whether the identified one or more linked accounts are authorized for receiving the patient-specific healthcare data; and in response to determining that the one or more linked accounts are authorized, transmitting the patient-specific healthcare data to the at least one entity.

13. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

receiving the patient-specific healthcare data from at least one input data source; storing the patient-specific healthcare data in a healthcare digital filing cabinet; receiving data sharing rules from a patient owner of the healthcare digital filing cabinet; and automatically transmitting the determined amount of the patient-specific healthcare data according to the received data sharing rules, wherein the data sharing rules include at least one of a physician sharing rule, a hospital sharing rule, or an implant manufacture sharing rule, wherein the data sharing rules include at least one a patient identifier setting, a data type sharing rule, or a meta data setting.

14. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

determining whether the patient-specific healthcare data is associated with the patient-specific medical implant; and in response to determining that the patient-specific healthcare data is associated with the patient-specific medical implant, transmitting at least a portion for the patient-specific healthcare data for a physician managing treatment

involving the patient-specific medical implant, wherein the patient-specific healthcare data includes one or more scans of the patient.

15. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

storing the patient-specific healthcare data in a healthcare digital filing cabinet;
linking accounts from multiple entities related to the patient-specific healthcare data into the healthcare digital filing cabinet.

16. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

encrypting the patient-specific healthcare data prior to transmission.

17. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

integrating input data sources of the patient-specific medical implant for the patient-specific healthcare data.

18. The non-transitory computer-readable medium of claim 11, wherein the patient-specific medical implant is a blockchain-enabled medical implant that is implanted in the body of a patient, wherein the operations further comprise:

establishing the communicative contact using the proximity communication mode;
and
accessing, based on the authentication level, a private key stored on the blockchain-enabled medical implant to access the patient-specific healthcare data in a healthcare digital filing cabinet.

19. The non-transitory computer-readable medium of claim 11, wherein the patient-specific healthcare data is locked such that the user cannot initially access the patient-specific healthcare data, wherein the operations further comprise:

receiving authentication information from the user;
authenticating the user based on the received authentication information; and

in response to authenticating the user, unlocking a portion of the patient-specific healthcare data.

20. The non-transitory computer-readable medium of claim 11, wherein the operations further comprise:

notifying the user of locking of a healthcare digital filing cabinet that contains the patient-specific healthcare data.

21. A computer-implemented method for providing patient-specific healthcare data from an implant, the method comprising:

establishing a communicative contact with a patient-specific medical implant implanted in a body of a patient by a device associated with a user using a proximity communication mode,

wherein the patient-specific medical implant contains patient-specific healthcare data;

receiving, by the user, a request to access the patient-specific healthcare data in the patient-specific medical implant;

determining, based on an authentication level associated with the user, an amount of the patient-specific healthcare data to provide to the user; and

transmitting, to the device of the user from the patient-specific medical implant, the determined amount of the patient-specific healthcare data.

22. The computer-implemented method of claim 21, further comprising:

identifying one or more linked accounts from at least one entity related to the patient-specific healthcare data and the patient-specific medical implant;

determining whether the identified one or more linked accounts are authorized for receiving the patient-specific healthcare data; and

in response to determining that the one or more linked accounts are authorized, transmitting the patient-specific healthcare data to the at least one entity.

23. The computer-implemented method of claim 21, further comprising:

receiving the patient-specific healthcare data from at least one input data source;

storing the patient-specific healthcare data in a healthcare digital filing cabinet;

receiving data sharing rules from a patient owner of the healthcare digital filing cabinet; and
automatically transmitting the determined amount of the patient-specific healthcare data according to the received data sharing rules.

24. The computer-implemented method of claim 23, wherein the data sharing rules include at least one of a physician sharing rule, a hospital sharing rule, or an implant manufacture sharing rule.

25. The computer-implemented method of claim 23, wherein the data sharing rules include at least one a patient identifier setting, a data type sharing rule, or a meta data setting.

26. The computer-implemented method of claim 21, further comprising:
determining whether the patient-specific healthcare data is associated with the patient-specific medical implant; and
in response to determining that the patient-specific healthcare data is associated with the patient-specific medical implant, transmitting at least a portion for the patient-specific healthcare data for a physician managing treatment involving the patient-specific medical implant.

27. The computer-implemented method of claim 21, wherein the patient-specific healthcare data includes one or more scans of the patient.

28. The computer-implemented method of claim 21, further comprising:
storing the patient-specific healthcare data in a healthcare digital filing cabinet;
linking accounts from multiple entities related to the patient-specific healthcare data into the healthcare digital filing cabinet.

29. The computer-implemented method of claim 21, further comprising:
encrypting the patient-specific healthcare data prior to transmission.

30. The computer-implemented method of claim 21, further comprising:
integrating input data sources of the patient-specific medical implant for the
patient-specific healthcare data.
31. The computer-implemented method of claim 21, wherein the authentication
level requires a two-factor authentication.
32. The computer-implemented method of claim 21, wherein the authentication
level of the user is based on a geolocation, biometric data, or authentication credentials.
33. The computer-implemented method of claim 21, wherein the patient-
specific medical implant is a blockchain-enabled medical implant that is implanted in the
body of a patient, the method further comprising:
establishing the communicative contact using the proximity communication mode;
and
accessing, based on the authentication level, a private key stored on the
blockchain-enabled medical implant to access the patient-specific
healthcare data in a healthcare digital filing cabinet.
34. The computer-implemented method of claim 21, wherein the user is a
healthcare provider or a patient.
35. The computer-implemented method of claim 21, wherein the patient-
specific healthcare data is locked such that the user cannot initially access the patient-
specific healthcare data, the method further comprising:
receiving authentication information from the user;
authenticating the user based on the received authentication information; and
in response to authenticating the user, unlocking a portion of the patient-specific
healthcare data.
36. The computer-implemented method of claim 35, wherein the authentication
information indicates the authentication level.

37. The computer-implemented method of claim 21, further comprising:
receiving authentication information;
determining the authentication information is not valid; and
in response to determining the authentication information is not valid, locking a
healthcare digital filing cabinet that contains the patient-specific healthcare
data.

38. The computer-implemented method of claim 21, further comprising
notifying the user of locking of a healthcare digital filing cabinet that contains the patient-
specific healthcare data.

39. A computer-implemented method for providing patient-specific healthcare
data associated with a patient-specific medical implant, the method comprising:
receiving the patient-specific healthcare data of a patient from at least one input
data source;
generating, based on the patient-specific healthcare data, a patient-specific
interactive surgical plan for implanting the patient-specific medical implant
in a body of the patient;
receiving, from a user, a request to modify the patient-specific interactive surgical
plan;
determining, based on an authentication level of the user, whether the user is
authorized to modify the patient-specific interactive surgical plan;
in response to determining the user is authorized to modify the patient-specific
interactive surgical plan, displaying, via a user-interface, the patient-
specific interactive surgical plan;
detecting a modification to the patient-specific interactive surgical plan by the user;
modifying the patient-specific interactive surgical plan based on the modification
of the patient-specific interactive surgical plan by the user, wherein a design
and placement of the patient-specific medical implant is modified; and
storing the modified patient-specific interactive surgical plan in a healthcare digital
filing cabinet.