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### Surgical visualization systems and related methods

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#### Abstract

Surgical visualization systems and related methods are disclosed herein, e.g., for providing visualization during surgical procedures. Systems and methods herein can be used in a wide range of surgical procedures, including spinal surgeries such as minimally-invasive fusion or discectomy procedures. Systems and methods herein can include various features for enhancing end user experience, improving clinical outcomes, or reducing the invasiveness of a surgery. Exemplary features can include access port integration, hands-free operation, active and/or passive lens cleaning, adjustable camera depth, and many others.

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## **Background/Summary**

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present application is a continuation of U.S. Ser. No. 17/740,305, filed May 9, 2022. U.S. Ser. No. 17/740,305 is a continuation of U.S. application Ser. No. 15/901,435, filed on Feb. 21, 2018, now issued as U.S. Pat. No. 11,344,190. U.S. application Ser. No. 15/901,435 is a continuation-in-part of U.S. application Ser. No. 15/692,845, filed on Aug. 31, 2017, now issued as U.S. Pat. No. 11,331,090. U.S. application Ser. No. 15/692,845 claims priority to U.S. Provisional Application No. 62/468,475, filed on Mar. 8, 2017. U.S. application Ser. No. 15/692,845 is also a continuation-in-part of U.S. application Ser. No. 15/437,792, filed on Feb. 21, 2017, and now issued as U.S. Pat. No. 10,874,425. U.S. application Ser. No. 15/437,792 is a continuation-in-part of U.S. application Ser. No. 15/254,877, filed on Sep. 1, 2016, now issued as U.S. Pat. No. 10,987,129. U.S. application Ser. No. 15/254,877 claims priority to U.S. Provisional Application No. 62/214,297, filed on Sep. 4, 2015. The entire contents of each of these applications are incorporated by reference herein.

## FIELD

(1) Surgical visualization systems and related methods are disclosed herein, e.g., for providing visualization during surgical procedures, including minimally-invasive spinal procedures.

## BACKGROUND

(2) There are many instances in which it may be desirable to provide a surgeon or other user with visualization of a surgical site. While a number of surgical visualization systems have been developed, they are often heavy and cumbersome to use, difficult to clean or sterilize, or have properties that render them inadequate or impossible to use for many types of procedures. A spinal endoscope, for example, is typically used only in limited procedures, such as herniated disc repair and other pathologies that are reduced to a predictable, very small location. Such devices typically require very small, specialized tools with low output force and tissue processing capabilities. Such devices can require multiple human operators, with an assistant or other user holding and operating the visualization system while the surgeon uses both hands to perform the surgery. In addition, such devices can have a steep learning curve, as the visualization orientation may be dictated by instrument orientation, and therefore may be constantly changing over the course of the procedure.

## SUMMARY

(3) Surgical visualization systems and related methods are disclosed herein, e.g., for providing visualization during surgical procedures. Systems and methods herein can be used in a wide range of surgical procedures, including spinal surgeries such as minimally-invasive fusion or discectomy procedures. Systems and methods herein can include various features for enhancing end user experience, improving clinical outcomes, or reducing the invasiveness of a surgery. Exemplary features can include access port integration, hands-free operation, active and/or passive lens cleaning, adjustable camera depth, and many others.

(4) In some embodiments, a surgical system can include an access device having a working channel and a visualization channel; and a visualization system at least partially disposed in the visualization channel, the visualization system comprising a camera module and a housing in which the camera module is mounted.

(5) The camera module can include an image sensor and a lens configured to direct reflected light onto the image sensor, the image sensor and the lens being disposed within the housing. The camera module can include an optical fiber having a distal end disposed within the housing and a proximal end in optical communication with a light source. The lens can be disposed within a lens lumen of a lens barrel and the optical fiber can be disposed in an illumination lumen of the lens barrel. The illumination lumen can be disposed closer to the center of the access device working channel than the lens lumen. The lens barrel can include a distal-facing surface that is obliquely angled relative to a central longitudinal axis of the working channel. The system can include a diffuser mounted in a recess formed in the distal-facing surface of the lens barrel over the optical fiber. The recess can be crescent-shaped and can substantially follow the perimeter of the lens lumen. A central region of the lens can be coated with hydrophobic coating and a peripheral region of the lens can be coated with a hydrophilic coating.

(6) The housing can include a main body and a distal end cap. The main body can include a camera lumen in which the camera module is disposed and first and second fluid lumens. The camera lumen can be disposed centrally in the main body, between the first and second fluid lumens. A distal facing surface of the main body and a distal facing surface of the end cap can be obliquely angled relative to a central longitudinal axis of the working channel. The main body can have a sidewall having a concave inner surface disposed adjacent the working channel and a convex outer surface disposed opposite the inner surface. The inner surface of the sidewall of the main body can define at least a portion of an inner surface of the working channel. The outer surface of the sidewall can include first and second planar regions connected by a central transition region that defines a section of a cylinder, the transition region following an outer perimeter of a camera lumen

of the main body. The inner surface can be concavely curved and connected to the outer surface by first and second transition regions that define sections of respective cylinders, the first and second transition regions following the outer perimeters of first and second fluid lumens formed in the main body. The housing can be formed from an inner circular tube disposed within and attached to an outer oval tube to define a camera lumen and first and second fluid lumens. The housing can be formed from an inner circular tube having opposed first and second outer shells attached thereto to define a camera lumen and first and second fluid lumens. The end cap can include a cut-out axially aligned with a lens of the camera module and a cut-out axially aligned with an illumination system of the camera module. A proximal-facing surface of the end cap can define a recess configured to direct fluid flowing out of a first fluid lumen of the housing across a lens of the camera module and into a second fluid lumen of the housing. The recess can include lateral end portions axially aligned with the first and second fluid lumens and medial end portions that are open to a cut-out of the end cap.

(7) The system can include a connector assembly extending from the housing, the connector assembly including electrical and optical connections to the camera module and fluid connections to the housing. The connector assembly can have an exterior shape that matches that of the housing. The system can include a controller having an electronic display configured to display image data captured by an image sensor of the camera module. The visualization channel can intersect or overlap with the working channel. The housing and the camera module can be axially-translatable relative to the access device. The visualization channel can have a central longitudinal axis disposed radially outward from a central longitudinal axis of the working channel.

(8) The access device can include a mating feature configured to selectively hold the visualization system in a desired position relative to the access device. The mating feature can include a locking track configured to receive a portion of the visualization system to restrict movement of the visualization system relative to the access device. The locking track can be formed in a proximal extension of the access device. The locking track can receive the visualization system in a snap-fit or friction fit. The mating feature can include an adjustment track configured to receive at least a portion of the visualization system to allow movement of the visualization system relative to the access device. The visualization system can be configured such that the visualization system can be loaded into the locking track by moving it radially outward from a central longitudinal axis of the visualization channel. The locking track can be curved or obliquely angled away from a central longitudinal axis of the visualization channel. The visualization system can be configured such that the visualization system can be secured to the mating feature at any point along a connector assembly of the visualization system. The mating feature can include a wheel that, when rotated, advances or retracts the visualization system relative to the access device. The mating feature can include a coil spring clamp configured to selectively lock the visualization system in a fixed position relative to the access device. The mating feature can include an O-ring disposed around a portion of the visualization system and a cone movably coupled to the access device, the cone being movable between a first position in which it expands the O-ring to allow movement of the visualization system relative to the access device and a second position in which the O-ring is released to clamp onto the visualization system and prevent movement of the visualization system relative to the access device.

(9) The system can include a sleeve insertable through the working channel of the access device, the sleeve having an outside diameter and a bulb movably coupled to the sleeve, the bulb being movable between a first position in which the bulb is disposed entirely within the outside diameter of the sleeve and a second position in which at least a portion of the bulb protrudes out from the outside diameter of the sleeve. The bulb in the second position can be configured to fill a void space within the access device distal to the visualization channel of the access device. The bulb can include a distal-facing surface that is curved or ramped to form a gradual transition between a cylindrical dilator inserted through the sleeve and an outer surface of the access device. The bulb

can be movable between the first and second positions by translating the sleeve axially relative to the access device. The bulb can be movable between the first and second positions by rotating the sleeve relative to the access device. The bulb can be biased towards the second position. The access device can include a transition portion at a distal end thereof, the transition portion being movable between a first position in which the transition portion extends radially-inward to provide a gradual transition between a cylindrical dilator inserted through the working channel and an outer surface of the access device and a second position in which the transition portion is moved radially-outward from the first position. The system can include a dilation shaft insertable through the access device to move the transition portion to the second position. The transition portion can include a plurality of flexible and resilient fingers.

(10) In some embodiments, a visualization system can include a camera module having an image sensor and a lens; and a housing in which the camera module is disposed, the housing having a main body, first and second fluid channels, and an end cap configured to direct fluid flow through the channels across the lens of the camera module.

(11) The camera module can include an optical fiber having a distal end disposed within the housing and a proximal end in optical communication with a light source. The lens can be disposed within a lens lumen of a lens barrel and the optical fiber can be disposed in an illumination lumen of the lens barrel. The system can include a diffuser mounted in a recess formed in a distal-facing surface of the lens barrel over the optical fiber. The recess can be crescent-shaped and can substantially follow the perimeter of the lens lumen. A central region of the lens can be coated with a hydrophobic coating and a peripheral region of the lens can be coated with a hydrophilic coating.

(12) The camera module can be disposed centrally in the main body, between the first and second fluid channels. A distal facing surface of the main body and a distal facing surface of the end cap can be obliquely angled relative to a central longitudinal axis of the camera module. The main body can have an outer surface that includes first and second planar regions connected by a central transition region that defines a section of a cylinder, the transition region following an outer perimeter of a camera lumen of the main body. The main body can have an inner surface that is concavely curved and connected to the outer surface by first and second transition regions that define sections of respective cylinders, the first and second transition regions following the outer perimeters of the first and second fluid channels. The housing can be formed from an inner circular tube disposed within and attached to an outer oval tube to define a camera lumen and the first and second fluid channels. The housing can be formed from an inner circular tube having opposed first and second outer shells attached thereto to define a camera lumen and the first and second fluid channels. The end cap can include a cut-out axially aligned with the lens. A proximal-facing surface of the end cap can define a recess configured to direct fluid flowing out of the first fluid channel of the housing across the lens and into the second fluid channel of the housing. The recess can include lateral end portions axially aligned with the first and second fluid channels and medial end portions that are open to the cut-out of the end cap.

(13) The system can include a connector assembly extending from the housing, the connector assembly including electrical and optical connections to the camera module and fluid connections to the housing. The connector assembly can have an exterior shape that matches that of the housing. The system can include a controller having an electronic display configured to display image data captured by an image sensor of the camera module.

(14) In some embodiments, a surgical method can include inserting an access device into a patient; mounting the access device to an anchor, the anchor comprising at least one of an anatomical structure of the patient and an implant implanted in the patient; inserting a camera module into the access device; adjusting a depth of the camera module relative to the access device; and securing the camera module to a mating feature of the access device to maintain the camera module at the adjusted depth.

(15) The anchor can include a bone anchor implanted in a pedicle of the patient. The method can

include performing a surgical procedure through the access device without using hands to hold the access device or the camera module. The method can include inserting a fusion cage through the access device and into an intervertebral disc space. Inserting the access device can include positioning a distal end of the access device in proximity to an intervertebral disc space of the patient via a TLIF approach. The method can include positioning the camera module in a relatively proximal position relative to the access device, performing a bone resection through the access device, positioning the camera module in a relatively distal position relative to the access device, and removing disc tissue through the access device. The method can include directing cleaning media through a housing in which the camera module is disposed and across a lens of the camera module. Inserting the access device can include positioning a distal end of the access device in a dry environment of the patient. Inserting the access device can include positioning a distal end of the access device in a sinus cavity of the patient. The method can include performing a laryngoscopy or a bronchoscopy using the camera module.

(16) In some embodiments, a surgical system can include an access device having a working channel and a visualization channel; a visualization system at least partially disposed in the visualization channel, the visualization system comprising a camera module and a housing in which the camera module is mounted; and a tissue shield that extends distally beyond a terminal distal end surface of the housing.

(17) The tissue shield can be longitudinally movable relative to the housing. The tissue shield can be slidably disposed within a lumen of the housing. The tissue shield can be slidably disposed within a lumen of the access device. The tissue shield can be slidably disposed along an exterior surface of the housing. The tissue shield can include a wiper configured to clear debris from a lens of the camera module as the tissue shield is moved longitudinally relative to the housing. The tissue shield can extend around less than an entire periphery of the housing. The tissue shield can include a curved inner surface that follows a curve of a lens of the camera module. The tissue shield can have an outer surface with a profile that matches that of an outer surface of the housing. The tissue shield can have a crescent-shaped transverse cross section.

(18) In some embodiments, a surgical system can include an access device having a working channel and a visualization channel; a visualization system at least partially disposed in the visualization channel, the visualization system comprising a camera module and a housing in which the camera module is mounted; and an active lens cleaning device configured to remove debris from a lens of the camera module.

(19) The lens cleaning device can include a source of positive pressure gas directed towards the lens through a lumen of the housing. The gas can include air or carbon dioxide. The lens cleaning device can include a fluid lumen having a nozzle opening through which fluid can be directed towards the lens, the nozzle opening being obliquely angled with respect to a central longitudinal axis of the housing. The nozzle opening can be formed in a tube that extends from a terminal distal end surface of the housing. The lens cleaning device can include a fluid lumen having a nozzle opening through which fluid can be directed towards the lens, the nozzle opening extending perpendicular to a central longitudinal axis of the housing. The lens cleaning device can include an ultrasound agitator. The lens cleaning device can include a membrane movable relative to the lens. The membrane can include a continuous loop of material configured to be carried across at least one of a wiper, a brush, a fluid jet, and a vacuum port to clean the membrane. The membrane can be rolled onto a spool. The membrane can extend through a first lumen of the housing, across the lens, and through a second lumen of the housing. The lens cleaning device can include a wiper at least partially disposed in the working channel of the access device. The wiper can include an offset portion that contacts a protrusion formed in the working channel to urge a tip of the wiper laterally across the lens as a shaft of the wiper is moved longitudinally within the working channel. The wiper can be biased towards the visualization channel such that the wiper wipes across the lens of the camera module as the camera module is advanced distally into the visualization channel.

(20) In some embodiments, a surgical method can include inserting an access device into a patient; inserting a housing having a camera module therein into the access device, the camera module having a lens; and while the access device and camera module are inserted into the patient, actuating a lens cleaning device to clean a visualization path to the lens of the camera module.

(21) Actuating the lens cleaning device can include moving a tissue shield protruding from a distal end of the housing longitudinally relative to the housing to carry a wiper across the lens. Actuating the lens cleaning device can include directing positive pressure air through a lumen of the housing and towards the lens. Actuating the lens cleaning device can include vibrating the lens. Actuating the lens cleaning device can include moving a membrane relative to the lens. Moving the membrane can include rotating a continuous loop of membrane material to move a soiled portion of the membrane away from the lens and to position a clean portion of the membrane over the lens. Actuating the lens cleaning device can include advancing the camera module through the access device to drag a wiper flap biased towards the visualization channel across the lens. Actuating the lens cleaning device can include moving a wiper longitudinally within the working channel, thereby causing an offset portion of the wiper to contact a protrusion disposed in the working channel to urge a tip of the wiper laterally across the lens.

(22) In some embodiments, a visualization system can include a camera module having an image sensor and a lens; and a housing in which the camera module is disposed, the housing having a main body, one or more fluid channels, and an end cap configured to direct fluid flow through the one or more fluid channels across the lens of the camera module.

(23) In some embodiments, a surgical system can include an access device having a working channel and a visualization channel; and a visualization system at least partially disposed in the visualization channel, the visualization system comprising a camera module; wherein the visualization system is axially translatable relative to the access device to position the visualization system such that the camera module protrudes from a distal end of the access device.

(24) In some embodiments, a surgical method can include inserting an access device into a patient; inserting a camera module into the access device; and adjusting a depth of the camera module relative to the access device; wherein adjusting the depth of the camera module comprises positioning the camera module such that the camera module protrudes from a distal end of the access device.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is a perspective view of a surgical visualization system and an access device;
- (2) FIG. 2A is a perspective view of a camera module of the system of FIG. 1;
- (3) FIG. 2B is a sectional side view of the camera module of FIG. 2A;
- (4) FIG. 2C is a sectional perspective view of the camera module of FIG. 2A;
- (5) FIG. 3A is a perspective view of a housing of the system of FIG. 1, with the housing shown as transparent and with the camera module of FIG. 2A disposed therein;
- (6) FIG. 3B is a perspective view of the distal end of the housing and camera module of FIG. 3A;
- (7) FIG. 3C is a perspective view of the housing of FIG. 3A;
- (8) FIG. 3D is a side view of the housing of FIG. 3A;
- (9) FIG. 3E is a sectional perspective view of the housing and camera module of FIG. 3A, adjacent a distal end thereof;
- (10) FIG. 3F is a perspective view of the distal end of the housing and camera module of FIG. 3A;
- (11) FIG. 3G is a partially exploded perspective view of the housing and camera module of FIG. 3A;
- (12) FIG. 3H is a perspective view of the housing and camera module of FIG. 3A, with an end cap

of the housing shown as transparent and schematically illustrating fluid flow through the housing;

(13) FIG. 3I is a sectional side view of the housing and camera module of FIG. 3A;

(14) FIG. 3J is a sectional perspective view of the housing and camera module of FIG. 3A;

(15) FIG. 4A is a perspective view of a connector assembly of the system of FIG. 1;

(16) FIG. 4B is a sectional perspective view of the connector assembly of FIG. 4A, adjacent a distal end thereof;

(17) FIG. 5A is a perspective view of a controller of the system of FIG. 1;

(18) FIG. 5B is a schematic block diagram of the controller of FIG. 5A;

(19) FIG. 6A is a perspective view of the system of FIG. 1 disposed in an access device, with the access device shown as transparent;

(20) FIG. 6B is a side view of the system and access device of FIG. 6A, with the access device shown as transparent;

(21) FIG. 6C is a perspective view of the system and access device of FIG. 6A, with the system disposed in a locking track of the access device;

(22) FIG. 6D is a perspective view of the system and access device of FIG. 6A, with the system disposed in an adjustment track of the access device;

(23) FIG. 6E is a sectional side view of the system and access device of FIG. 6A;

(24) FIG. 6F is a sectional side view of the distal end of the system and access device of FIG. 6A;

(25) FIG. 6G is a top view of the system and access device of FIG. 6A;

(26) FIG. 6H is a sectional top view of the system and access device of FIG. 6A;

(27) FIG. 7 is a perspective view of a surgical system, including the visualization system of FIG. 1, in use to perform a surgical procedure on a patient's spine;

(28) FIG. 8 is a sectional side view of the camera module of FIG. 2A, schematically illustrating viewing properties of the camera module;

(29) FIG. 9 is a perspective view of the distal end of another exemplary housing;

(30) FIG. 10A is a sectional top view of another exemplary housing;

(31) FIG. 10B is a sectional top view of another exemplary housing;

(32) FIG. 11A is a sectional perspective view of another exemplary housing;

(33) FIG. 11B is a perspective view of the housing of FIG. 11A;

(34) FIG. 11C is a sectional perspective view of the housing of FIG. 11A;

(35) FIG. 11D is a sectional perspective view of the housing of FIG. 11A;

(36) FIG. 12A is a sectional top view of another exemplary housing;

(37) FIG. 12B is an exploded and assembled view of another exemplary housing;

(38) FIG. 13 is a side view of a mating feature that can be included in the access devices herein;

(39) FIG. 14 is a perspective view of another mating feature that can be included in the access devices herein;

(40) FIG. 15A is a sectional side view of another mating feature that can be included in the access devices herein, shown in locked state;

(41) FIG. 15B is a sectional side view of the mating feature of FIG. 15A, shown in an unlocked state;

(42) FIG. 16A is a perspective view of another mating feature that can be included in the access devices herein;

(43) FIG. 16B is a sectional side view of the mating feature of FIG. 16A;

(44) FIG. 16C is a perspective view of the mating feature of FIG. 16A;

(45) FIG. 17 is a perspective view of another mating feature that can be included in the access devices herein;

(46) FIG. 18 is a perspective view of another mating feature that can be included in the access devices herein;

(47) FIG. 19 is a perspective view of another mating feature that can be included in the access devices herein;



(48) FIG. 20 is a perspective view of the system of FIG. 1, shown with a user control;

(49) FIG. 21A is a sectional perspective view of an access device and a standard dilator;

(50) FIG. 21B is a perspective view of an access device and a dilation system;

(51) FIG. 21C is a sectional perspective view of the access device and dilation system of FIG. 21B;

(52) FIG. 21D is a perspective view of a sleeve of the dilation system of FIG. 21B;

(53) FIG. 22A is a proximal-facing end view of an access device and a dilation system in a first configuration;

(54) FIG. 22B is a proximal-facing end view of the access device and dilation system of FIG. 22A in a second configuration;

(55) FIG. 23A is a perspective view of an access device;

(56) FIG. 23B is a sectional perspective view of the access device of FIG. 23A;

(57) FIG. 23C is a bottom view of the access device of FIG. 23A;

(58) FIG. 23D is a top view of the access device of FIG. 23A;

(59) FIG. 23E is a perspective view of a dilation shaft configured for use with the access device of FIG. 23A;

(60) FIG. 23F is a sectional perspective view of the dilation shaft of FIG. 23E inserted into the access device of FIG. 23A;

(61) FIG. 23G is a perspective view of the dilation shaft of FIG. 23E inserted into the access device of FIG. 23A;

(62) FIG. 24A is a perspective view of a visualization system;

(63) FIG. 24B is a perspective view of a housing, camera module, and mating feature of the visualization system of FIG. 24A;

(64) FIG. 24C is a perspective view of the mating feature of the visualization system of FIG. 24A;

(65) FIG. 25A is a perspective view of the distal end of a housing having an angled nozzle opening;

(66) FIG. 25B is a side view of the distal end of the housing of FIG. 25A;

(67) FIG. 25C is a perspective view of the distal end of a housing having a wiper deployable from a nozzle opening of the housing;

(68) FIG. 26A is a perspective view of the distal end of a housing having a tissue shield;

(69) FIG. 26B is a detail perspective view of the distal end the housing of FIG. 26A;

(70) FIG. 26C is a perspective view of the distal end of a housing having a movable tissue shield;

(71) FIG. 26D is a perspective view of the distal end of a housing having a movable tissue shield with an integrated wiper;

(72) FIG. 27A is a sectional side view of a camera module having an ultrasound agitator;

(73) FIG. 27B is a sectional perspective view of another camera module having an ultrasound agitator;

(74) FIG. 28A is a sectional side view of a housing having a movable membrane;

(75) FIG. 28B is a sectional side view of another housing having a movable membrane;

(76) FIG. 29A is a bottom view of an access device having a mechanical wiper, with the wiper shown in a first lateral position;

(77) FIG. 29B is a bottom view of the access device and mechanical wiper of FIG. 29A, with the wiper shown in a second lateral position;

(78) FIG. 29C is a sectional side view of the access device and mechanical wiper of FIG. 29A, with the wiper shown in the first lateral position;

(79) FIG. 29D is a sectional side view of the access device and mechanical wiper of FIG. 29A, with the wiper shown in the second lateral position;

(80) FIG. 30A is a sectional side view of an access device having a mechanical wiper, with the wiper shown in a first position; and

(81) FIG. 30B is a sectional side view of the access device and mechanical wiper of FIG. with the wiper shown in a second position.

DETAILED DESCRIPTION

(82) Surgical visualization systems and related methods are disclosed herein, e.g., for providing visualization during surgical procedures. Systems and methods herein can be used in a wide range of surgical procedures, including spinal surgeries such as minimally-invasive fusion or discectomy procedures. Systems and methods herein can include various features for enhancing end user experience, improving clinical outcomes, or reducing the invasiveness of a surgery. Exemplary features can include access port integration, hands-free operation, active and/or passive lens cleaning, adjustable camera depth, and many others.

(83) Certain exemplary embodiments will now be described to provide an overall understanding of the principles of the structure, function, manufacture, and use of the devices and methods disclosed herein. One or more examples of these embodiments are illustrated in the accompanying drawings. Those skilled in the art will understand that the devices and methods specifically described herein and illustrated in the accompanying drawings are non-limiting exemplary embodiments. The features illustrated or described in connection with one exemplary embodiment may be combined with the features of other embodiments.

(84) In some embodiments, the surgical visualization systems disclosed herein can enable hands free visualization. For example, a camera module can be mounted in an access device in a manner that eliminates the need for a surgeon, assistant, or other user to manually hold the camera in place. As another example, the access device can be secured to a support, e.g., an operating table, an anatomical anchor, or the like, eliminating the need for the user to manually hold the access port, or to hold a camera module disposed therein. Accordingly, the user's hands can be free to perform other steps of the surgery.

(85) The camera module can be separate and independent from surgical instruments used to carry out the procedure. Accordingly, the instruments with which the visualization system can be used are not restricted, and the system can be used with any of a variety of custom or off-the-shelf instruments. Such instruments can include instruments with increased size, strength, output force, and/or tissue processing capabilities. In addition, the visual trajectory of the camera can be independent of instrument positioning. This can allow the camera, and/or an access device in which the camera is disposed, to remain relatively stationary as instruments are manipulated and as the procedure is carried out. The field of view of the camera can thus remain substantially fixed during the procedure, providing the user with good spatial orientation and providing a reduced learning curve as compared to other visualization systems.

(86) Traditional spinal microscopes can protrude significantly from the patient, occupy a lot of space over a surgical incision, and a clear space must be maintained around the proximal end of the scope to allow a user to look through the scope. This can limit the degree to which other instruments can be manipulated during the surgery, for example limiting the possible access angles of the instruments. This can also restrict the size and types of instruments that can be used, the placement of the user's hands during various steps in the surgery, and so forth. Visualization systems of the type described herein can be integrated with an access device, can have a low-profile design, and/or can display captured images on an external monitor, reducing or eliminating these potential concerns.

(87) In some embodiments, the surgical visualization systems disclosed herein can enable adjustment of the depth of a camera within an access device. In some embodiments, the camera depth can be quickly and easily adjusted. In some embodiments, the camera depth can be adjusted with one hand in a tool-free manner. The ability to easily adjust camera depth can allow visualization to be optimized for each stage of a surgical procedure in a seamless manner that does not interfere with or disrupt the surgical flow. In a spinal surgery, for example, the camera can be retracted proximally when performing gross bone removal and other steps that are relatively low risk, but could cause the camera lens to become obscured with debris. Later, when doing nerve work or other tasks that require greater precision, the camera can be advanced distally within the access device. In some cases, the camera can be advanced to protrude from the distal end of the

access device, e.g., to position the camera within an intervertebral disc space.

(88) In some embodiments, the surgical visualization systems disclosed herein can provide improved visualization in harsh or challenging operating environments. In many spinal procedures, for example, the operating environment is dry (as compared to fluid filled cavities that exist in other surgeries where visualization systems are used) and a large amount of smoke and cutting debris can be generated during the surgery. The surgical visualization systems disclosed herein can include active and/or passive features for clearing such debris from the camera lens, or for preventing such debris from blocking or sticking to the lens in the first place. In some embodiments, the surgical visualization systems disclosed herein can provide high-resolution visualization in minimally-invasive spinal procedures, such as endoscopic transforaminal lumbar interbody fusion (TLIF) procedures.

(89) In some embodiments, the surgical visualization systems disclosed herein can be a single-use disposable, can be easily cleanable or sterilizable, can have a low-profile, can be lightweight, can be low-cost, can have high resolution, and/or can be used in minimally-invasive surgery, e.g., spinal surgery.

(90) FIG. 1 illustrates an exemplary surgical visualization system **100**. The system **100** can include a camera module **102** disposed within a housing **104**. The housing **104** can be configured for positioning at a surgical site or in proximity to a surgical site. The system **100** can include a controller or display **106** for controlling the camera module **102**, for displaying images captured by the camera module, and so forth. The camera module **102** and/or the housing **104** can be coupled to the controller **106** by a connector or connector assembly **108**. The connector assembly **108** can include electrical and/or optical connections to the camera module **102**. The connector assembly **108** can include fluid connections to the housing **104**. The fluid connections can be used to deliver material to the housing **104**, to withdraw material from the housing, or to both deliver and withdraw material from the housing, e.g., for cleaning a lens of the camera module **102**. The system **100** can be selectively mountable to an access device **110** or other support, can be used independently, can be selectively mountable to a surgical robot or connector arm, can be insertable through a surgical instrument, or can be used in various other ways to facilitate a surgical procedure.

(91) The camera module **102** is shown in greater detail in FIGS. 2A-2C. The camera module **102** can include an image sensor **112** for capturing images of a field disposed in view of the image sensor, e.g., images of a surgical site. The image sensor **112** can be configured to convert light directed onto the image sensor into an electronic signal. The image sensor **112** can be configured to capture full color still and video images. The image sensor **112** can be configured to capture 1080p high definition video. The image sensor **112** can be a full-frame image sensor. The image sensor **112** can be a charge-coupled-device (CCD) image sensor, a complementary-metal-oxide-semiconductor (CMOS) image sensor, an N-type metal-oxide-semiconductor (NMOS) image sensor, a video chip, a chip-on-tip camera, and/or can use various other image sensing technologies. The image sensor **112** can be a monochromatic sensor having a pixel array and supporting circuitry that are sensitive to electromagnetic radiation of any wavelength. Exemplary image sensors **112**, and other features that can be included or incorporated in the camera module **102**, are disclosed in U.S. patent application Ser. No. 13/952,518 entitled CONTINUOUS VIDEO IN A LIGHT DEFICIENT ENVIRONMENT (issued as U.S. Pat. No. 10,568,496); U.S. patent application Ser. No. 14/214,412 entitled IMAGE ROTATION USING SOFTWARE FOR ENDOSCOPIC APPLICATIONS (issued as U.S. Pat. No. 10,362,240); U.S. Pat. No. 8,648,932 entitled SYSTEM, APPARATUS AND METHODS FOR PROVIDING A SINGLE USE IMAGING DEVICE FOR STERILE ENVIRONMENTS; U.S. Pat. No. 8,952,312 entitled IMAGE SENSOR FOR ENDOSCOPIC USE; U.S. Pat. No. 8,972,714 entitled SYSTEM AND METHOD FOR PROVIDING A SINGLE USE IMAGING DEVICE FOR MEDICAL APPLICATIONS; U.S. Pat. No. 9,123,602 entitled PIXEL ARRAY AREA OPTIMIZATION USING STACKING

SCHEME FOR HYBRID IMAGE SENSOR WITH MINIMAL VERTICAL INTERCONNECTS; U.S. Pat. No. 9,153,609 entitled IMAGE SENSOR WITH TOLERANCE OPTIMIZING INTERCONNECTS; U.S. Pat. No. 9,462,234 entitled CAMERA SYSTEM WITH MINIMAL AREA MONOLITHIC CMOS IMAGE SENSOR; U.S. Pat. No. 9,509,917 entitled WIDE DYNAMIC RANGE USING MONOCHROMATIC SENSOR; and U.S. Pat. No. 9,622,650 entitled SYSTEM AND METHOD FOR SUB-COLUMN PARALLEL DIGITIZERS FOR HYBRID STACKED IMAGE SENSOR USING VERTICAL INTERCONNECTS, each of which is incorporated herein by reference.

(92) The camera module **102** can include a lens or optical element **114** configured to direct light onto the image sensor **112**. The lens **114** can be a static lens. The lens **114** can be a monolithic block of optically-transparent material. The lens **114** can be polymeric. The lens **114** can have a fixed focal length or can have an adjustable focal length. The lens **114** can include a mechanical shutter. The lens **114** can include multiple optical elements movable relative to one another. The lens **114** can include one or more motors, actuators, gears, etc. for adjusting the focal length, aperture size, shutter speed, and other parameters of the lens. The camera module **102** can include a modular lens receiver such that a user can attach any of a variety of lenses to the camera module. Exemplary lenses **114** can include prime lenses, normal lenses, wide-angle lenses, fisheye lenses, telephoto lenses, zoom lenses, anamorphic lenses, catadioptric lenses, lenses of varying focal lengths or varying ranges of focal lengths, etc. The lens **114** can include a high speed autofocus. The lens **114** can include an adjustable aperture and an adjustable shutter speed.

(93) The camera module **102** can include an illumination system for illuminating a field of view of the image sensor **112**. The illumination system can include a digital or analog light source. The light source can include one or more laser emitters or light-emitting diodes, an incandescent bulb, or the like. The light source can emit light in any dithered, diffused, or collimated emission and can be controlled digitally or through analog methods or systems. The light source can be pulsed to illuminate a surgical scene. The light source can pulse in one or more partitions, where each partition is a pre-determined range of wavelengths of the electromagnetic spectrum that is less than the entire electromagnetic spectrum. The pixel array of the image sensor **112** can be paired with the light source electronically, such that they are synced during operation for both receiving emissions of reflected electromagnetic radiation and for the adjustments made within the system. The light source can be tuned to emit electromagnetic radiation. The light source can pulse at an interval that corresponds to the operation and functionality of the pixel array. The light source can pulse light in a plurality of electromagnetic partitions, such that the pixel array receives reflected electromagnetic energy and produces a data set that corresponds (in time) with each specific electromagnetic partition. For example, the light source can emit a green electromagnetic partition, a blue electromagnetic partition, and a red electromagnetic partition in any desired sequence which can be combined to form a color image. Any color combination or any electromagnetic partition can be used in place of the red partition, green partition, and blue partition, such as cyan, magenta, and yellow, ultraviolet, infra-red, or any other combination, including all visible and non-visible wavelengths. Exemplary illumination systems, and other features that can be included or incorporated in the camera module **102**, are disclosed in U.S. Pat. No. 9,516,239 entitled YCBCR PULSED ILLUMINATION SCHEME IN A LIGHT DEFICIENT ENVIRONMENT; and U.S. Pat. No. 9,641,815 entitled SUPER RESOLUTION AND COLOR MOTION ARTIFACT CORRECTION IN A PULSED COLOR IMAGING SYSTEM, each of which is incorporated herein by reference.

(94) The light source can be disposed within the housing **104**, or can be disposed remotely from the housing. For example, the illumination system can include an optical fiber **116** having a distal end disposed within or in close proximity to the housing **104** and a proximal end in optical communication with a light source disposed remotely from the housing. The optical fiber **116** can direct light emitted from the light source into the field of view of the image sensor **112**. The

illumination system can include an optical element **118** for adjusting various illumination properties. Exemplary optical elements **118** can include diffusers, filters, and so forth. In the illustrated embodiment, the camera module **102** includes an optical element **118**, which is illustrated as a diffuser, disposed over the terminal distal end of an optical fiber **116**.

(95) The camera module **102** can include a printed circuit board assembly (PCBA) **120**. The image sensor **112** can be mounted directly to the PCBA **120**, or can be operably coupled thereto, e.g., using a connector **122**. The PCBA **120** can include power conditioning circuitry, hardware logic, clocks, and/or other components for operating the image sensor **112** and communicating image data generated by the image sensor to the controller **106**.

(96) One or more of the above camera module **102** components can be mounted in a frame or lens barrel **124**. The lens barrel **124** can include an outer sidewall having one or more channels or lumens formed therein. For example, as shown, the lens barrel **124** can include a lens lumen **126** and an illumination lumen **128**.

(97) The lens lumen **126** can include proximal and distal ends **126p**, **126d** and a central longitudinal axis **A1**. The lens lumen **126** can have a circular transverse cross-section. The lens **114** can be disposed within a distal end of the lens lumen **126**. The image sensor **112** can be positioned at or in a proximal end of the lens lumen **126**. The lens lumen **126** can be open at its proximal and distal ends and closed along its sides as shown, or a portion or all of the lens lumen can be open to an outer sidewall of the lens barrel **124**.

(98) The illumination lumen **128** can include proximal and distal ends **128p**, **128d** and a central longitudinal axis **A2**. The illumination lumen **128** can have a circular transverse cross-section. The optical fiber **116** can be disposed within the illumination lumen **128**. The illumination lumen **128** can be open at its proximal and distal ends and closed along its sides or, as shown, a portion or all of the illumination lumen can be open to an outer sidewall of the lens barrel **124**. This can facilitate insertion of the optical fiber **116** into the lens barrel **124** during assembly, e.g., by allowing the optical fiber to be side-loaded or laterally-inserted into the illumination lumen **128**. The distal end of the illumination lumen **128** can be curved or angled, e.g., such that it extends in a direction that is not parallel to the axis **A2**. This arrangement can allow a planar distal end of a straight-cut optical fiber **116** to be oriented parallel to an angle-cut distal end of the lens barrel **124**, as shown. In other arrangements, the optical fiber **116** can be angle-cut to match the distal end of the lens barrel **124**.

(99) The lumens **126**, **128** can be coaxial with one another or can be non-coaxial. For example, the lumens **126**, **128** can be laterally offset from each other. The lumens **126**, **128** can be formed such that they extend parallel to one another, e.g., such that their respective central longitudinal axes **A1**, **A2** are parallel. As described further below, when integrated with an access device **110**, the illumination lumen **128** can be disposed radially-inward from the lens lumen **126**, e.g., such that the illumination lumen is disposed closer to the center of the access device working channel than the lens lumen. This can provide a more even distribution of light within the working channel of the access device **110**.

(100) The proximal end of the lens barrel **124** can include a recess or pocket **130**. The image sensor **112** can be disposed within the recess **130**. An image sensor connector **122** and/or at least a portion of the PCBA **120** can be disposed within the recess **130**. The lens barrel **124** can include an internal baffle **132** disposed between the lens **114** and the image sensor **112**. The baffle **132** can include an aperture through which light passing through the lens **114** can be communicated to the image sensor **112**. The aperture can have a fixed dimension or can be mechanically-adjustable.

(101) The lens barrel **124** can include a distal-facing surface at a terminal distal end thereof. The lumens **126**, **128** of the lens barrel **124** can be open to the distal-facing surface. The distal facing surface can be obliquely angled. For example, the distal facing surface can lie substantially in a plane that is obliquely angled with respect to the central axis **A1** of the lens lumen **126**, obliquely angled with respect to the central axis **A2** of the illumination lumen **128**, and/or obliquely angled

with respect to the central longitudinal axis of a working channel or access device in which the camera module **102** is disposed. The lens **114** can be flush with the distal-facing surface as shown, or can be recessed or protruding therefrom. The distal-facing surface can include a recess **134** in which the diffuser or other optical element **118** of the illumination system can be disposed. The recess **134** can be formed about the perimeter of the illumination lumen **128**. The recess **134**, and the optical element **118** disposed therein, can have a curved or crescent shape as shown. The recess **134** can include an inner edge that follows or substantially follows the perimeter of the lens lumen **126**.

(102) As described further below, when integrated with an access device **110**, the distal-facing surface of the lens barrel **124** can be angled, in a distal-to-proximal direction, towards the center of the access device or a working channel thereof in which the camera module **102** is disposed. This can provide a better view of the surgical site for the image sensor **112** and/or a more even distribution of light within the surgical site. The lens barrel **124** can have a transverse exterior cross-section that is oval, oblong, circular, elliptical, square, rectangular, etc.

(103) As shown in FIGS. 3A-3J, the camera module **102** can be mounted in the housing **104**. The housing **104** can include a main body **136** and a distal end cap **138**. As described further below, the end cap **138** can be configured to direct the fluid across the lens **114** and/or the illumination system of the camera module **102**, e.g., to clear obstructions therefrom. The housing **104** can be rigid or flexible. The housing **104** can be made as short as possible to facilitate positioning of the housing within an access device **110**. The housing **104** can have a length that is less than about 60 mm. For example, the housing **104** can have a length of about 45 mm or that is less than about 45 mm.

(104) The main body **136** of the housing **104** can include a proximal-facing surface **136p**, a distal-facing surface **136d**, and a sidewall **136s** connecting the proximal-facing and distal-facing surfaces. One or more channels or lumens can be formed in the main body **136**. The main body **136** can be formed by extrusion of a multi-lumen shaft. The main body **136** can be formed by welding or otherwise attaching multiple longitudinal components to one another.

(105) The main body **136** can include a camera lumen **140** in which the camera module **102** can be selectively mounted. At least a portion of the camera lumen **140** can be lined with or can otherwise include a metallic tube, which can provide electromagnetic shielding for the components of the camera module **102**.

(106) The main body **136** can include one or more fluid lumens **142**. For example, in the illustrated embodiment, the main body **136** includes a first fluid lumen **142A**, which can be used to convey material from a proximal end of the housing **104** to a distal end of the housing, and a second fluid lumen **142B**, which can be used to convey material from a distal end of the housing to the proximal end of the housing. While first and second fluid lumens **142** are shown, the housing **104** can include any number of fluid lumens. The first and second lumens **142** can form part of a lens cleaning system in which cleaning fluid or media is delivered through one lumen to deliver the cleaning fluid to the distal end of the camera module **102** and suction or vacuum is applied to the other lumen to draw cleaning fluid, tissue, debris, or other material away from the camera module. In some embodiments, a fluid such as air or other gas can be directed towards the lens under positive pressure. The positive pressure fluid can be conveyed through one or more of the lumens **142**. Each of the lumens **142** can include a fluid connector or coupling **144** at a proximal end thereof for establishing fluid communication between the lumens and the connector assembly **108**. The fluid connectors **144** can be male barbed fittings that extend proximally from the proximal-facing surface **136p** of the main body **136** as shown, or can be any other type of fluid fitting or connection, such as a luer connection, a female fitting, etc. Multiple different types of cleaning media can be delivered through the same lumen or through separate lumens. The multiple types of cleaning media can be delivered simultaneously, sequentially, intermittently, or otherwise. In one example, a spray of saline or other liquid can be directed through a lumen to the lens, and can be chased with a burst of carbon dioxide or other gas through the same lumen. In another example, the

liquid and gas can be delivered through separate lumens. In some embodiments, the housing can include only a single fluid lumen.

(107) The lumens **140**, **142** of the housing **104** can be co-axial, non-coaxial, or some lumens can be coaxial while others are non-coaxial. The camera lumen **140** can be disposed centrally between first and second fluid lumens **142** as shown. The lumens **140**, **142** of the housing **104** can be parallel to one another. The lumens **140**, **142** can have various shapes. The lumens **140**, **142** can have a transverse interior cross-section that is oval, oblong, circular, elliptical, square, rectangular, etc. The camera lumen **140** can have an interior shape that matches the exterior shape of the camera module **102**, or the lens barrel **124** thereof.

(108) The distal facing surface **136d** of the main body **136** can be obliquely angled. For example, the distal facing surface **136d** can lie substantially in a plane that is obliquely angled with respect to a central longitudinal axis A3 of the housing **104** and/or obliquely angled with respect to the central longitudinal axis of a working channel or access device in which the housing is disposed. The distal-facing surface **136d** of the main body **136** can be angled in the same manner as the distal-facing surface of the camera module **102** or lens barrel **124**. The distal-facing surface of the camera module **102** can be flush with the distal-facing surface **136d** of the main body **136**, or can be recessed or protruding relative thereto.

(109) The sidewall **136s** of the housing **136** can have any of a variety of shapes. The sidewall **136s** can have a transverse exterior cross-section that is substantially triangular, crescent shaped, circular, square, or rectangular. The sidewall **136s** can be cylindrical. The sidewall **136s** can be curved. The sidewall **136s** can be shaped to facilitate integration of the housing **104** with an access device **110**, e.g., to reduce or eliminate the degree to which the housing interferes with a working channel of the access device. The sidewall **136s** can include an inner portion **136i** that is concave. The inner portion **136i** can be curved. The inner portion **136i** can form a section of a working channel of an access device **110**, e.g., a cylindrical or elliptical working channel. The sidewall **136s** can include an outer portion **136o** that is convex. The outer portion **136o** can be curved. As shown for example in FIG. 3E, the sidewall **136s** can include an outer portion **136o** having first and second planar regions connected by a central transition region that defines a section of a cylinder. The transition region can follow the outer perimeter of the camera lumen **140**. As also shown for example in FIG. 3E, the sidewall **136s** can include an inner portion **136i** that is concavely curved and connected to the outer portion **136o** by first and second transition regions that define sections of respective cylinders. The first and second transition regions can follow the outer perimeters of the fluid lumens **142**.

(110) The end cap **138** of the housing **104** can be coupled to the distal end of the main body **136**. An exterior sidewall of the end cap **138** can have a shape that matches that of the sidewall of the main body **136**. The end cap **138** can include one or more cut-outs **146** formed therein. The end cap **138** can include a first cut-out **146A** aligned with the lens **114** of the camera module **102** to allow light to pass through the end cap and into the lens. The end cap **138** can include a second cut-out **146B** aligned with the illumination system of the camera module **102** to allow light to pass through the end cap and into the surgical site. The first and second cut-outs **146** can be discrete cut-outs or can be contiguous as shown. The first and second cut-outs **146** can be circular, can have a shape that matches that of the lens **114** or illumination system, or can be otherwise shaped to function as described above. A proximal-facing surface of the end cap **138** can include one or more recesses, grooves, or channels **148** for directing fluid flow. Alternatively, the proximal-facing surface of the end cap **138** can be a flat planar surface and the recesses, grooves, or channels **148** can be formed in the distal-facing surface of the main body **136**. Lateral endportions of the recesses **148** can be axially aligned with the fluid lumens **142** of the main body **136**. Medial endportions of the recesses **148** can be open to the cut-outs **146** and/or to the distal-facing surface of the lens **114** and the illumination system. In use, as shown in FIG. 3H, fluid exiting the first lumen **142A** of the main body **136** can be directed by the end cap **138** across the lens **114** and the illumination system (e.g.,

the diffuser or optical element **118** of the illumination system) and towards the distal entrance of the second fluid lumen **142B**, e.g., along the path of the illustrated arrows. It will be appreciated that fluid can alternatively be directed in an opposite direction. The recesses **148** can include baffles, nozzles, diverters, or other structures for tailoring the flow of fluid across the lens **114** and/or the illumination system. In some embodiments, fluid flow can be substantially contained to the interior of the end cap, e.g., without irrigating the surgical site or a working channel of an access device in which the housing **104** is mounted. Containing the fluid flow in this manner can be particularly useful in “dry environment” procedures such as a lumbar TLIF procedure. Containing the fluid flow can help limit bleeding and possible tissue damage. In other embodiments, the fluid is not contained to the end cap and can be used to irrigate the surgical site and/or working channel.

(111) The housing **104** and/or the camera module **102** can be coupled to the controller **106** via a connector or connector assembly **108**. An exemplary connector assembly **108** is shown in FIGS. **4A-4B**. The connector assembly **108** can include one or more conductors therein. The connector assembly **108** can include fluid conductors for delivering fluid to or from the housing **104**. The connector assembly **108** can include optical conductors for delivering light to or from the camera module **102**. The connector assembly **108** can include electrical conductors for communicating image data, control signals, or other information between the controller **106** and the camera module **102**. The conductors can be disposed partially or entirely within an outer sheath **150** of the connector assembly **108**.

(112) The connector assembly **108** can include a distal section **108d** and a proximal section **108p**. In the distal section **108d**, all of the conductors of the connector assembly **108** can be disposed within the outer sheath **150**. In the proximal section **108p**, one or more of the conductors can exit the outer sheath **150** and can extend separately therefrom. For example, in the illustrated embodiment, the distal section **108d** of the connector assembly **108** includes electrical conductors **152A**, one or more optical fibers **152B**, and first and second fluid lumens **152C** all extending through a common outer sheath **150**. Also in the illustrated embodiment, the proximal section **108p** of the connector assembly **108** is configured such that the electrical conductors **152A** and one or more optical fibers **152B** continue through the common outer sheath **150** while the first and second fluid lumens **152C** exit the outer sheath as discrete fluid tubes **154**. The outer sheath **150** can include a mechanical connector **156** at a proximal end thereof for making optical and/or electrical connections with the controller **106**. The fluid tubes **154** can include respective fluid fittings or connectors for making fluid connections, e.g., with a fluid reservoir and/or vacuum source or positive pressure source of the controller **106** or separate from the controller.

(113) The distal section **108d** of the connector assembly **108** can have an exterior shape that matches that of the housing **104**, e.g., as shown in FIG. **4B**. The distal section **108d** of the connector assembly **108** can mate with the housing **104** to define a seamless exterior transition. At least a portion of the connector assembly **108** can be flexible or bendable. As described further below, the distal section **108d** of the connector assembly **108** can be flexible to facilitate integration of the system **100** with an access device **110**.

(114) An exemplary controller **106** is shown in FIGS. **5A-5B**. Although an exemplary controller **106** is depicted and described herein, it will be appreciated that this is for sake of generality and convenience. In other embodiments, the controller **106** may differ in architecture and operation from that shown and described here. The controller **106** can be a tablet computer, mobile device, smart phone, laptop computer, desktop computer, cloud-based computer, server computer, and so forth. The controller **106** can include a processor **156** for controlling operation of the controller **106**, for example by executing embedded software, operating systems, device drivers, application programs, and so forth. The processor **156** can be or can include one or more microprocessors, microcontrollers, ASICs, FPGAs, PICs, processors that read and interpret program instructions from internal or external memory or registers, and so forth. The controller **106** can include a memory **158**, which can provide temporary or permanent storage for code to be executed by the



processor **156** or for data that is processed by the processor. The memory **158** can include read-only memory (ROM), flash memory, one or more varieties of random access memory (RAM), and/or a combination of memory technologies. The various components of the controller **106** can be interconnected via any one or more separate traces, physical busses, communication lines, etc.

(115) The controller **106** can include an interface **160**, such as a communication interface or an I/O interface. A communication interface can enable the controller **106** to communicate with remote devices (e.g., other controllers or computer systems) over a network or communications bus (e.g., a universal serial bus). An I/O interface can facilitate communication between one or more input devices, one or more output devices, and the various other components of the controller **106**.

Exemplary input devices include touch screens, mechanical buttons, keyboards, and pointing devices. The controller **106** can include a storage device **162**, which can include any conventional medium for storing data in a non-volatile and/or non-transient manner. The storage device **162** can include one or more hard disk drives, flash drives, USB drives, optical drives, various media disks or cards, and/or any combination thereof. The controller **106** can include a display **164**, and can generate images to be displayed thereon. The display **164** can be an electronic display, a vacuum fluorescent display (VFD), an organic light-emitting diode (OLED) display, or a liquid crystal display (LCD). The controller **106** can include a power supply **166** and appropriate regulating and conditioning circuitry. Exemplary power supplies include batteries, such as polymer lithium ion batteries, or adapters for coupling the controller **106** to a DC or AC power source (e.g., a USB adapter or a wall adapter).

(116) The controller **106** can include a fluid source **168** that can be in fluid communication with a fluid lumen **152C** of the connector assembly **108** when the connector assembly is attached to the controller **106**. The fluid source **168** can include a reservoir of cleaning media. The cleaning media can be a flowable gas or liquid. The cleaning media can include one or more of carbon dioxide, saline, oxygen, air, water, and the like. The fluid source can include a source of positive pressure air or other gas. The fluid source **168** can include a pump or other mechanism for urging cleaning media through the connector assembly **108** and the housing **104**. The pump can be controlled by the processor **156** to execute a cleaning cycle. The cleaning cycle can be executed automatically, or in response to a user instruction. For example, the processor **156** can detect user actuation of a button, foot pedal, or other interface element and initiate a cleaning cycle in response thereto.

(117) The controller **106** can include a light source **170** that can be optically coupled to an optical fiber **152B** of the connector assembly **108** when the connector assembly is attached to the controller. Exemplary light sources include light-emitting diodes (LEDs), incandescent or fluorescent bulbs, etc.

(118) The controller **106** can include a vacuum or suction source **172** that can be in fluid communication with a fluid lumen **152C** of the connector assembly **108** when the connector assembly is attached to the controller. The controller **106** can include an onboard vacuum pump for generating suction, or can be configured to attach to a standard hospital or operating room vacuum supply. The suction source **172** can include a valve, regulator, or other component for adjusting the degree of suction applied to the housing **104** and/or for turning the suction on or off. The suction source **172** can be controlled by the processor **156**, e.g., to execute a cleaning cycle. The cleaning cycle can be executed automatically, or in response to a user instruction. For example, as noted above, the processor **156** can detect user actuation of a button, foot pedal, or other interface element and initiate a cleaning cycle in response thereto.

(119) The controller **106** can include one or more connectors **174** for mating with the connector **156** and/or the fluid couplings **154** of the connector assembly **108**. When mated, the connectors can establish electrical, optical, and/or fluid connections between the controller **106** and the connector assembly **108**. It will be appreciated that any one or more of the components above can be disposed external to the housing of the controller **106**, and/or can be separate or isolated from the controller altogether. For example, any one or more of the fluid source **168**, the light source **170**, and the

suction source **172** can be external to and/or separate from the controller **106**.

(120) The controller **106** can receive image data from the image sensor **112**. The image data can be communicated via a wired or wireless connection. The image data can include still image data and/or video image data. The controller **106** can display the image data on an on-board display **164** of the controller, or on one or more external monitors or displays operably coupled to the controller. The image data can be displayed to a surgeon or other user to facilitate a surgical procedure. The controller **106** can display patient data, user interface controls for manipulating system settings, controls for capturing screen shots of displayed images, and so forth.

(121) The various functions performed by the controller **106** can be logically described as being performed by one or more modules. It will be appreciated that such modules can be implemented in hardware, software, or a combination thereof. It will further be appreciated that, when implemented in software, modules can be part of a single program or one or more separate programs, and can be implemented in a variety of contexts (e.g., as part of an embedded software package, an operating system, a device driver, a standalone application, and/or combinations thereof). In addition, software embodying one or more modules can be stored as an executable program on one or more non-transitory computer-readable storage mediums.

(122) The system **100** can be configured to be integrated or used with an access device. Exemplary access devices can include cannulas, retractors, tubes, and other structures for providing a working channel in a surgical application. The access device can define a working channel that extends from a surgical site, e.g., an intervertebral disc space or a spinal region proximate thereto, to a location outside a patient's body. The access device can include a visualization channel for receiving the housing **104** and the camera module **102** of the visualization system **100**. The visualization channel can also receive at least a portion of the connector assembly **108**. The visualization channel can be the same as the working channel, can be independent of the working channel, or can overlap or intersect with the working channel. At least a portion of the sidewall of the working channel can be defined by an exterior surface of the housing **104**. The housing **104** and/or the camera module **102** can be disposed off-center within the access device. The housing **104** and/or the camera module **102** can be slidably and/or rotatably coupled to the access device.

(123) The housing **104** and/or the camera module **102** can be axially translatable within the access device, e.g., in a proximal-distal direction, to adjust the depth of the camera module relative to the access device. For example, the housing **104** can be advanced distally relative to the access device to move the lens **114** and image sensor **112** closer to the surgical site. By way of further example, the housing **104** can be retracted proximally relative to the access device to move the lens **114** and image sensor **112** farther from the surgical site. The ability to reposition the camera module **102** within the access device can facilitate various surgical procedures. For example, in an exemplary TLIF procedure, the camera module **102** can be positioned relatively shallow within the access device when cutting through Kambin's triangle and can then be advanced deeper within the access device when performing subsequent discectomy. In some cases, the camera module **102** can be advanced distally into the disc space. The camera module **102** can be advanced distally so as to protrude or extend from a distal end of an access device while the access device is inserted into a patient. For example, the camera module **102** can be advanced such that the lens **114** and/or the image sensor **112** is disposed outside of and distal to a terminal distal end of the access device. The camera module **102** can be advanced or retracted to any of an infinite number of relative longitudinal positions with respect to the access device. The ability to reposition the camera module **102** can also allow the camera module to be a modular component interchangeably usable with many different types or sizes of access device, or with an adjustable-length access device.

(124) An exemplary access device **110** is shown in FIGS. 6A-6H. The access device **110** can include an elongate body having proximal and distal ends.

(125) The access device **110** can define a working channel **174** extending between the proximal and distal ends and having a central longitudinal axis **A4**. The working channel **174** can be cylindrical.

The working channel **174** can have a circular transverse cross-section. The working channel **174** can have a diameter in the range of about 3 mm to about 30 mm, in the range of about 10 mm to about 20 mm, and/or in the range of about 12 mm to about 15 mm. The working channel **174** can have a diameter of about 15 mm. While a single working channel **174** is shown, the access device **110** can include any number of working channels. In use, instruments and/or implants can be disposed in, passed through, and/or inserted into the working channel **174** to perform a surgical procedure. In some embodiments, the access device **110** can be used to access an intervertebral disc space. A cutting instrument can be inserted through the working channel **174** to cut tissue, such as bone or disc tissue. An aspiration instrument can be inserted through the working channel **174** to aspirate material from the disc space, including excised bone or disc tissue. The cutting instrument and the aspiration instrument can be a single tool. An implant such as a fusion cage, a height and/or width expandable fusion cage, a disc prosthesis, or the like can be inserted into the disc space through the working channel **174**.

(126) The access device **110** can define a visualization channel **176**. The visualization channel **176** can extend between the proximal and distal ends of the access device **110**, or can extend along less than an entire length of the access device. The visualization channel **176** can include a central longitudinal axis **A5**. The central axis **A5** of the visualization channel **176** can be disposed radially-outward from the central axis **A4** of the working channel **174**. The working channel **174** can have a greater transverse cross-sectional area than the visualization channel **176**. The visualization channel **176** can be open to, or can intersect with, the working channel **174** along its length. The visualization channel **176** can be isolated or separate from the working channel **174**.

(127) The visualization channel **176** can have an interior transverse cross section that matches or substantially matches the exterior transverse cross-section of the housing **104**. When disposed within the visualization channel **176**, an exterior surface of the housing **104** can define at least a portion of the inner sidewall of the working channel **174**. The working channel **174** can be cylindrical about the central axis **A4** and the surface of the housing **104** that faces the working channel can form a section of a cylinder centered on the axis **A4**. The inner sidewall of the working channel **174** and the outer surface of the housing **104** can define a substantially smooth and continuous surface.

(128) The access device **110** can include an attachment feature **180**, e.g., for attaching the access device to a support or other object. The attachment feature **180** can be formed at a proximal end of the access device **110**. For example, the access device **110** can include an annular circumferential groove **180** formed in an exterior surface thereof.

(129) The access device **110** can include a mating feature **178** for stabilizing, holding, and/or attaching the visualization system **100** to the access device. The mating feature **178** can be a proximal extension of the access device **110** as shown. The mating feature **178** can define one or more tracks **182** configured to receive the connector assembly **108** therein. The tracks **182** can be open to one side such that the connector assembly **108** can be loaded laterally into the track, e.g., by moving the connector assembly away from the central axis **A5** of the visualization channel **176**. Alternatively, or in addition, the connector assembly **108** can be loaded into the mating feature **178** by translating the connector assembly proximally or distally relative thereto.

(130) One or more of the tracks **182** can define a connector path that is curved or obliquely-angled away from the central axis **A5** of the visualization channel **176**. The track **182** can have an interior transverse cross-section that matches or substantially matches the exterior transverse cross-section of the connector assembly **108**. The track **182** can extend around the outer periphery of the connector assembly **108**. The track **182** can extend around the connector assembly **108** to a sufficient degree that the free edges of the track interfere slightly with side-loading of the connector assembly into the track. Accordingly, slight deformation or deflection of the connector assembly **108** and/or the mating feature **178** can be required to load the connector assembly into the track **182**. This can allow the connector assembly **108** to be held securely by the mating feature **178**, e.g.,

by “snapping” the connector assembly into the track **182**.

(131) The mating feature **178** can include inner and outer tracks **182A**, **182B**, e.g., as shown in FIGS. **6C**, **6D**, and **6G**. The tracks **182** can include interfering edges of the type described above to restrict movement of the connector assembly **108** into and out of the tracks, but to allow such movement when sufficient force is applied, e.g., when the user specifically intends to perform such movement. The inner track **182A** can be axially aligned with the visualization channel **176**, or aligned therewith to a greater extent than the outer track **182B**. The outer track **182B** can be curved, obliquely angled, or otherwise axially offset from the visualization channel **176**. When disposed in the inner track **182A**, as shown in FIG. **6D**, the connector assembly **108** can be retained to the access device **110**, while still being able to translate proximally or distally relative to the access device with relatively little friction. When disposed in the outer track **182B**, as shown in FIG. **6C**, proximal-distal translation of the connector assembly **108** relative to the access device **110** can be limited or prevented, e.g., due to the curve of the connector assembly and/or due to increased friction between the connector assembly and the access device. In use, the connector assembly **108** can be positioned in the inner track **182A** to adjust the height of the camera module **102** relative to the access device **110** and can be positioned in the outer track **182B** to hold the camera module securely in place at a fixed height relative to the access device.

(132) The connector assembly **108** can be secured to the mating feature **178** at any point along its length, e.g., at any point along the distal section **108d** of the connector assembly. Accordingly, the visualization system **100** can be locked to the access device **110** at any inserted depth of the camera module **102**. In addition, the visualization system **100** can be locked with the camera module **102** at a desired depth, regardless of the length of the access device **110**, the position of the mating feature **178** along the access device, etc. This can allow the visualization system **100** to be interchangeably used with any of a variety of different type or size access devices **110**.

(133) The ability to lock the system **100** to the mating feature **178** can allow the camera module **102** to be used in a hands-free manner. In other words, the surgeon or other user does not need to manually grasp and/or hold the camera module **102** in place during use. The mating feature **178** can provide for simple, quick, and/or one-handed depth adjustment of the camera module **102**, resulting in minimal delay and disruption to the procedure.

(134) The access device **110** can have an exterior transverse cross section that is circular, e.g., as shown in FIG. **6G**. The access device **110** can have an exterior transverse cross section that is oblong or egg-shaped, e.g., as shown in FIG. **6H**. The access device **110** can include any of a variety of other exterior transverse cross sectional shapes. The access device **110** can have an external diameter or dimension in the range of about 5 mm to about 30 mm, in the range of about 10 mm to about 25 mm, and/or in the range of about 15 mm to about 22 mm. The access device **110** can have an external diameter or dimension of about 17 mm. The exterior surface of the access device **110** can be roughened, ribbed, milled, or coated with or formed from a material having a high coefficient of friction, which can advantageously improve grip and stability with surrounding tissue when the access device is inserted into a patient.

(135) As noted above, and as shown in FIG. **6F**, when disposed in the access device **110**, the lens **114** of the camera module **102** can be aimed towards the central axis **A4** of the working channel **174**. Similarly, when so positioned, the illumination system of the camera module **102**, e.g., the optical fiber **116** and/or the optical element **118**, can be aimed towards the central axis **A4** of the working channel **174**. The illumination system can be disposed radially-outward from the central axis **A4** of the working channel **174** and the lens **114** can be disposed radially-outward from the illumination system.

(136) FIG. **7** illustrates an exemplary surgical system **10** in which the devices and methods described herein can be used, though it will be appreciated that such devices and methods can be used in various other applications instead or in addition. Further details on the system of FIG. **7** can be found in U.S. application Ser. No. 15/437,792, filed on Feb. 21, 2017 (issued as U.S. Pat. No.

10,874,425), which is hereby incorporated by reference herein. The system **10** can be used in various surgical procedures, including spinal surgeries such as microsurgical bone resection, spinal decompression, spinal fusion, and the like. In general, the system **10** can include any one or more of an access device **110**, a tissue retractor **12**, a pedicle post or other anchor **14**, a connector **16**, and a camera or visualization system **100**. The access device **110** can be any of the access devices described herein. The visualization system **100** can be any of the visualization systems described herein.

(137) An exemplary method of using the system **10** of FIG. 7 can include any one or more of the following steps, performed in any of a variety of sequences: a) making an incision in a skin of a patient; b) percutaneously inserting through the incision an access device **110** having a substantially tubular shape (such as a tube or a multi-slotted retractor), the access device having a length adapted to extend from the incision to a border between sensitive and insensitive tissue (e.g., a superior articular process (SAP), or a lamina) in the spine of the patient; c) stabilizing the access device to an anchor **14** (e.g., a pedicle anchor) using a connector **16**; d) inserting an access device integrated optical visualization system **100**, e.g., a visualization system of the type described herein; e) resecting a portion of the superior articular process, and/or performing a microsurgical decompression procedure; f) inserting or deploying a tissue retractor **12** through or from the access device so that a distal end portion of the tissue retractor extends to the intervertebral disc, the retractor having an outer surface; g) contacting the outer surface of the retractor to a nerve root to shield the nerve root; h) microsurgically decompressing any tissue deemed to be causing nerve impingement; i) extracting intervertebral disc material including removing cartilaginous material from the vertebral endplates; j) inserting an interbody device; and k) deploying a mechanism of stabilization to stabilize the intervertebral segment.

(138) Exemplary properties of the camera module **102** and the lens **114** thereof are shown in FIG. 8. The camera module **102** can have a field-of-view (FOV), a direction of view (DOV), and a depth of field (DOF). The FOV can be in the range of about 60 to about 70 degrees. The DOV can be in the range of about 15 to 30 degrees. The DOV can be in the range of about 20 to degrees. The DOV can be about 22.5 degrees. The DOF can be in the range of about 7 mm to about 40 mm.

(139) The system **100** can include active cleaning features. Active cleaning features can include application of an active force to the lens **114**, the illumination system, or other components of the camera module **102**. The active force can be or can include a fluid jet, fluid suction, mechanical or acoustic vibration, mechanical wipers, etc. The active force can be or can include positive pressure air or other gas directed towards, onto, and/or across the lens or other component(s) of the camera module.

(140) The system **100** can include passive cleaning features. The passive cleaning features can be used independently, or can augment or improve the performance of active cleaning features. As one example, the lens **114** can have a coating applied thereto to resist or prevent adhesion of debris to the lens. The coating can be hydrophilic. The coating can be oleophilic. The coating can be hydrophobic. The coating can be oleophobic. The coating can be a pollution-repellant coating. The coating can be a gradient coating, e.g., one in which a central region of the lens has a hydrophobic coating and a peripheral region of the lens has a hydrophilic coating. The gradient lens coating can be effective to “walk” or direct fluid from the center of the lens towards the outer periphery of the lens and out of the way of the image sensor **112**.

(141) As shown in FIG. 9, the fluid lumens **142** of the housing **104** can each include a respective nozzle **184** disposed at a distal end thereof. The end cap **138** of the housing **104** can be omitted in such arrangements. The nozzles **184** can be configured to aim or direct the flow of fluid and/or suction forces towards the lens **114** or the illumination system of the camera module **102**.

(142) FIG. 10A illustrates another exemplary transverse cross-section of the housing **104**. As shown, the fluid lumens **142** can be enlarged and can be non-circular. The fluid lumens **142** can be ear-shaped. The fluid lumens **142** can be asymmetrical.

(143) FIG. 10B illustrates another exemplary transverse cross-section of the housing **104**. As shown, the fluid lumens **142** can be crescent or banana shaped. The fluid lumens **142** can have a convex inner sidewall that follows the outer periphery of the camera lumen **140**.

(144) FIGS. 11A-11D illustrate the distal end of an alternative housing **104** having crescent-shaped fluid lumens **142**, an oval or oblong exterior transverse cross-section, and an end cap **138** with an oval or oblong central opening **146**.

(145) As noted above, the main body **136** of the housing **104** can be formed by welding or otherwise attaching multiple longitudinal components to one another. For example, as shown in FIG. 12A, an inner circular tube **136A** can be inserted into an outer oval tube **136B** to define a main body **136** having a central camera lumen **140** and first and second lateral fluid lumens **142**. The inner tube **136A** can be welded, adhered, or otherwise attached and/or sealed to the outer tube **136B**. By way of further example, as shown in FIG. 12B, opposed outer shells **136C** can be welded or otherwise attached to an inner tube **136A** to define a main body **136** having a central camera lumen **140** and first and second lateral fluid lumens **142**. The outer shells **136C** can include respective proximal fluid couplings **144** and inner channels that connect the fluid couplings to the void spaces **142** formed between the shells and the inner tube **136A** when the components are mated to each other. The arrangement shown in FIG. 12B can advantageously allow a complex housing cross-section to be formed within one or more simple welds of the two shells **136C** to the inner tube **136A** and/or to each other.

(146) FIG. 13 illustrates an exemplary mating feature **178A** for attaching the visualization system **100** to the access device **110**. The mating feature **178A** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the visualization system **100**. An actuation wheel or gear **186** can be rotatably mounted over the track **182**. The wheel **186** can be engaged with the connector assembly **108** such that rotation of the wheel advances or retracts the connector assembly relative to the access device **110**. The wheel **186** can allow for stageless and precise depth adjustment of the camera module **102**. The wheel **186** can include teeth, protrusions, or other surface features for enhancing user grip and/or friction between the wheel and the connector assembly **108**. The connector assembly **108** can include teeth or ridges that can be enmeshed with the teeth of the wheel **186**. The wheel **186** can be spring-biased into engagement with the connector assembly **108**. The gap between the wheel **186** and the track **182** can be open to one side, e.g., to allow side-loading of the connector assembly **108** into the gap. The user can thus perform gross depth adjustment of the camera module **102** in a freehand manner, and then insert the connector assembly **108** into the gap and use the wheel **186** to achieve fine depth adjustment.

(147) FIG. 14 illustrates an exemplary mating feature **178B** for attaching the visualization system **100** to the access device **110**. The mating feature **178B** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the visualization system **100**. The mating feature **178B** can include a clamp **188** that can be actuated by a user to selectively grasp or selectively release the connector assembly **108**. Any of a variety of types of clamps can be used, though in the illustrated embodiment, the mating feature **178B** includes a coil spring **188** that defines a central passage through which the connector assembly **108** can be inserted. The spring **188** can include handle levers that, when squeezed together, relax the tension of the spring and expand the diameter of the central passage to allow movement of the connector assembly **108** relative to the access device **110**. When the levers are released, the tension in the spring **188** can be increased to contract the diameter of the central passage and clamp down on the connector assembly **108**, thereby holding it in a fixed position relative to the access device **110**.

(148) FIGS. 15A-15B illustrate an exemplary mating feature **178C** for attaching the visualization system **100** to the access device **110**. The mating feature **178C** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the

visualization system **100**. The mating feature **178C** can include an O-ring **190** that defines a central passage through which the connector assembly **108** can be inserted. The O-ring **190** can be maintained in a fixed position relative to the extension **178C**, such that when the O-ring clamps down on a connector assembly **108** inserted therethrough, the connector assembly can be maintained at a fixed position relative to the extension. The extension **178C** can include a movable button **192** with a conical or ramped bearing surface. As shown in FIG. **15B**, pressing the button **192** into the extension **178C** (to the left in the drawing) can be effective to wedge the cone of the button into the O-ring **190**, thereby expanding the diameter of the O-ring and allowing movement of the connector assembly **108** relative to the extension. As shown in FIG. **15A**, when the button **192** is released, a spring **194** can urge the button outward (to the right in the drawing), withdrawing the cone from the O-ring **190** to allow the O-ring diameter to contract and clamp down on the connector assembly **108**, thereby holding it in a fixed position relative to the access device **110**. (149) FIGS. **16A-16C** illustrate an exemplary mating feature **178D** for attaching the visualization system **100** to the access device **110**. The mating feature **178D** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the visualization system **100**. The mating feature **178D** can be an angled click-type fastening system of the type described above. The mating feature **178D** can be optimized for use with a connector assembly **108** having a circular exterior transverse cross-section. The mating feature **178D** can include a longitudinally-oriented adjustment track **182A** and an obliquely- or laterally-oriented locking track **182B**.

(150) FIG. **17** illustrates an exemplary mating feature **178E** for attaching the visualization system **100** to the access device **110**. The mating feature **178E** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the visualization system **100**. The mating feature **178E** can be an angled click-type fastening system of the type described above. The mating feature **178E** can include a longitudinally-oriented adjustment track **182A** and an obliquely- or laterally-oriented locking track **182B**. The locking track **182B** can be spaced a distance apart and radially-outward from the main body of the access device **110** by a strut or beam **196**. The mating feature **178E** can be configured to contact the connector assembly **108** only at the locking track **182B**. The mating feature **178E** can be simple to manufacture and can accommodate a gradual bend radius of the connector assembly **108**.

(151) FIG. **18** illustrates an exemplary mating feature **178F** for attaching the visualization system **100** to the access device **110**. The mating feature **178F** can include a cut-out **198** formed in the proximal edge of the access device **110**. The mating feature **178F** can be a click-type fastening system of the type described above. The connector assembly **108** can be positioned within a longitudinally-oriented adjustment track **182A** of the mating feature **178F** to allow depth adjustment of the camera module **102**. The connector assembly **108** can be urged out of the adjustment track **182A** and into the cut-out **198** to apply sufficient friction to the connector assembly to limit or prevent depth adjustment of the camera module **102**. The cut-out **198** can be U-shaped. The cut-out **198** can be V-shaped. The mating feature **178F** can allow the connector assembly **108** to be routed away from the access device **110** at a greater angle and closer to the skin surface of the patient, reducing the overall profile of the system **100** and keeping the connector assembly out of the way of the surgeon or other user.

(152) FIG. **19** illustrates an exemplary mating feature **178G** for attaching the visualization system **100** to the access device **110**. The mating feature **178G** can include a proximal extension of the access device **110** having a track **182** for guiding or holding the connector assembly **108** of the visualization system **100**. The mating feature **178G** can include a lid or closure cap **101** pivotably coupled thereto, e.g., via a living hinge or flexible material properties of the extension. The lid **101** can be positioned in a closed state in which it clamps the connector assembly **108** to the extension to limit or prevent depth adjustment of the camera module **102**. The lid **101** can be positioned in an open state in which it does not engage the connector assembly **108**, or engages the connector

assembly to a lesser degree, such that the connector assembly is movable relative to the extension to adjust the depth of the camera module **102**. The lid **101** can be retained in the closed state, e.g., via a snap-lock, click-lock, or other locking structure. The lid **101** can include a lever **103** to facilitate release of the lid from the closed state.

(153) As shown in FIG. **20**, the visualization system **100** can include a user control **105**. The user control **105** can be disposed at any of a variety of locations along the visualization system **100**, e.g., along a distal portion of the connector assembly **108** as shown. During use, the user control **105** can be positioned within the sterile field. This can allow a surgeon or other user to actuate the control **105** directly, without having to leave the sterile field or rely on an assistant outside the sterile field. The control **105** can be operably coupled to the camera module **102**, to the controller **106**, to the fluid source **168**, to the light source **170**, and/or to the suction source **172**. Actuation of the control **105** can be effective to initiate a cleaning operation, to stop a cleaning operation, to capture an image, to rotate a display of images captured by the camera module **102**, to adjust a white balance of the displayed images, to adjust a brightness of the displayed images, to play or stop a recorded video, to zoom the displayed images in or out (optically and/or digitally), etc. The control **105** can include one or more push buttons. The control **105** can include one or more foot switches. The control **105** can include a hand pump or syringe for directing cleaning media towards the camera module **102**. The control **105** can include a remote control integrated into the connector assembly **108**. The control **105** can include a remote control coupled to the controller **106** via a wired or wireless connection.

(154) The access devices disclosed herein can be inserted into a patient using various dilation techniques. In an exemplary method, a guidewire or needle can be inserted through a percutaneous incision in the patient. The guidewire can be placed using fluoroscopic guidance, a surgical navigation system, freehand, or otherwise. The incision can be sequentially or serially dilated, for example by inserting one or more dilators over the guidewire, each having a progressively larger outside diameter. Once sufficiently dilated, the access device can be inserted by placing the outermost dilator into the working channel of the access device and sliding the access device distally along the dilator and into the patient. The one or more dilators can then be removed from the patient, leaving an open working channel through the access device through which the surgical procedure can be conducted.

(155) There can be instances in which it may be necessary or desirable to augment standard cylindrical dilation techniques. For example, as shown in FIG. **21A**, an access device **110** can include a cylindrical working channel **174** and an offset visualization channel **176**. The access device **110** can have a non-cylindrical exterior dimension. The visualization channel **176** can terminate a distance apart from the distal end of the access device **110**, leaving a void space **107** within the access device distal to the visualization channel. As shown, when a standard cylindrical dilator **109** is inserted through the working channel **174**, a sharp transition or step **111** can exist at the distal end of the access device **110** between the outer surface of the dilator and the outer surface of the access device adjacent the visualization channel **176**. In this example and/or in others, a dilation system can be used to facilitate insertion of the access device **110** and dilation of tissue disposed in the path of the visualization channel **176**.

(156) FIGS. **21B-21D** illustrate an exemplary dilation system. As shown, the system can include a sleeve **113** with a bulb **115** movably coupled thereto. When the sleeve **113** is disposed in the working channel **174** of the access device **110**, the bulb **115** can occupy the void space **107** in the access device and provide a smooth transition **117** between the outer surface of the dilator **109** and the outer surface of the access device adjacent the visualization channel **176**. Accordingly, the bulb **115** can minimize or eliminate the above-described step **111**.

(157) The sleeve **113** can be substantially cylindrical. The sleeve **113** can be hollow to define a channel **119** through which a standard cylindrical dilator **109** can be inserted. The sleeve **113** can define an outside diameter D. The bulb **115** can be movable relative to the sleeve **113** between a



first position in which the bulb is disposed entirely within the outside diameter D of the sleeve and a second position in which at least a portion of the bulb protrudes out from the outside diameter D of the sleeve. The bulb **115** can be biased towards the second position. The bulb **115** can be attached to or formed integrally with the sleeve **113**. The bulb **115** can be attached to the sleeve by a spring. For example, the bulb **115** can be mounted at the distal end of a longitudinal leaf spring or flat spring **121** of the sleeve **113**. The spring **121** can be an integral extension of the sleeve **113** defined between opposed longitudinal slits formed in the sleeve. The bulb **115** can include a distal-facing surface **115d** that is ramped, curved, tapered, or otherwise configured to provide a smooth lead-in between the outside diameter of a dilator **109** disposed in the sleeve **113** and the outside diameter of the access device **110**. The bulb **115** can include a proximal-facing surface **115p** that is ramped, curved, tapered, or otherwise configured to urge the bulb radially-inward towards the first position as the sleeve **113** is withdrawn proximally from the access device **110**.

(158) In use, an incision can be sequentially dilated using standard cylindrical dilators, including an outermost dilator **109**. The sleeve **113** can be loaded into the access device **110** with the bulb **115** disposed in the first, radially-inward position. The sleeve **113** can be advanced distally relative to the access device **110** until the bulb **115** is at the depth of the void space **107**, at which point the bulb can move radially-outward to the second position under the bias of the spring **121**. The bulb **115** can also be urged radially-outward, and maintained in that position, by insertion of a dilator **109** through the sleeve **113**. The access device **110** with the inserted sleeve **113** can then be advanced distally over the outer-most dilator **109**. As the access device **110** is advanced distally, the distal-facing surface **115d** of the bulb **115** can gently urge tissue out of the path of the access device. Once the access device **110** is positioned as desired, the dilators **109** can be removed from the sleeve **113** by withdrawing the dilators proximally therefrom. The sleeve **113** can also be removed from the access device **110** by withdrawing the sleeve proximally therefrom. As the sleeve **113** is withdrawn proximally relative to the access device **110**, the bulb **115** can be urged radially-inward, e.g., by the proximal-facing surface **115p** of the bulb **115** bearing against the distal end of the visualization channel **176**, thereby moving the bulb to the first, radially-inward position to allow the sleeve to be removed from the access device. The sleeve **113** can form a dilator having a profile at its distal end that differs from its profile at its proximal end.

(159) FIGS. **22A-22B** illustrate another exemplary dilation system in which the sleeve **113A** is configured to rotate relative to the access device **110** about the central longitudinal axis **A4** of the working channel **174**. The sleeve **113A** can have a longitudinal slit or other features for allowing the sleeve to expand and contract radially. The sleeve **113A** can be radially-contracted upon insertion into the access device **110** to bias the bulb **115A** radially-outward. The sleeve **113A** can be rotatable about the axis **A4** between a first position, shown in FIG. **22A**, in which the bulb **115** is rotationally offset from the void space **107** and thus deflected radially-inward by the inner sidewall of the working channel **174**, and a second position, shown in FIG. **22B**, in which the bulb is rotationally aligned with the void space such that the bulb springs radially-outward to fill the void space. In the first position, the bulb **115A** can be positioned such that it does not interfere with insertion or removal of the sleeve **113A** from the access device **110**. In the second position, the bulb **115A** can fill the void space **107** to provide a smooth transition between a dilator and the access device **110**, e.g., as described above. The sleeve **113A** can form a dilator having a profile at its distal end that differs from its profile at its proximal end.

(160) FIGS. **23A-23G** illustrate another exemplary dilation system. As shown, the distal end of the access device **110A** can include a ramped, curved, or tapered transition portion **123** that provides a smooth transition between a cylindrical dilator inserted through the working channel **174** of the access device and the outside surface of the access device adjacent the visualization channel **176**. The transition portion **123** can be flexible or bendable. The transition portion **123** can be movable between a first position in which the transition portion extends radially-inward to provide a smooth distal-facing dilation surface **123d** and a second position in which the transition portion is moved

radially-outward from the first position so as not to obstruct the field of view of a camera module mounted in the access device **110A**. The transition portion **123** can include one or more movable fingers **125**. The fingers **125** can be defined by a plurality of longitudinal slits formed in the outer wall of the access device **110A**. The fingers **125** can have resilient material properties, such that they are biased inwards towards the first position.

(161) The transition portion **123** can be moved between the first and second positions by a dilation shaft **127** insertable through the access device **110A**. The dilation shaft **127** can include a distal shroud **129** configured to contact and bear against the transition portion **123** as the dilation shaft is advanced distally within the access device **110A** to urge the transition portion radially outward. The shroud **129** can form a section of a cylinder as shown. At least a portion of the visualization channel **176** can be formed in the dilation shaft **127**. The dilation shaft **127** can remain in place within the access device **110** when the camera module **102** is disposed in the access device and as the surgical procedure is performed.

(162) FIGS. **24A-24C** illustrate an auxiliary visualization system **100A**. The system **100A** can be used independently, or can be used with the visualization system **100** described above. The system **100A** can include a camera module **102A**, housing **104A**, and connector assembly **108A**, each of which can include any of the features of the corresponding components of the system **100**. The system **100A** can be used as a freehand stylus-type or wand-type camera. The system **100A** can be inserted through a working channel of an access device while the system **100** is inserted through a visualization channel of the access device. Both cameras **100**, **100A** can be coupled to the same controller or display, or each can be coupled to an independent controller or display. Multiple auxiliary cameras **100A** can be used simultaneously. In the case of a spinal surgery, the auxiliary camera **100A** can extend into the disc space and the primary camera **100** can remain within the access device. The auxiliary camera **100A** can be attached to the access device using a mating feature **131**. The mating feature **131** can be configured to hold or support the auxiliary camera **100A** relative to an access device. The mating feature **131** can allow hands-free operation of the auxiliary camera **100A**. As shown in FIG. **24C**, the mating feature **131** can include a C-shaped clip or other mechanism **133** for attaching to the housing or connector assembly of the auxiliary camera **100A**. The mating feature **131** can include any of the features described above with respect to mating features for attaching the visualization system **100** to an access device. The mating feature **131** can include a distal clip or springy strip **135** for attaching the mating feature to the proximal rim of an access device.

(163) FIGS. **25A-25B** illustrate an exemplary housing **104B** that can be used with the camera modules and/or access devices described herein. The housing **104B** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104B** can include one or more fluid lumens **142B**. The fluid lumen **142B** can include a nozzle **184B** disposed at a distal end thereof. The nozzle **184B** can be configured to aim or direct the flow of fluid and/or suction forces towards the lens **114** of the camera module **102**. The nozzle **184B** can be defined by a slot or cut-out **137** formed in the sidewall of a length of tubing that protrudes distally from the distal end of the housing **104B**. The slot **137** can allow fluid to flow between an interior of the lumen **142B** and a region adjacent to the distal end of a visualization channel, or a lens **114** or other component of a camera module **102** disposed therein. The slot **137** can be obliquely angled. For example, a major axis of the slot **137** can extend at an oblique angle with respect to a central longitudinal axis of the fluid lumen **142B**, a central longitudinal axis of the housing **104B**, and/or a central longitudinal axis of an access device or a visualization channel of an access device. In some embodiments, the slot **137** can extend at an angle B with respect to a transverse plane that is perpendicular to a central longitudinal axis of the housing **104B**. The angle B can be in the range of about 5 degrees to about 85 degrees. The angle B can be in the range of about 10 degrees to about 60 degrees. The angle B can be in the range of about 15 degrees to about 30 degrees. The angle B can be about 22.5 degrees. The angle of the slot **137** can be equal or substantially equal to a

corresponding angle of an oblique distal end of the housing **104B**, and/or an oblique distal end of the lens **114**. The slot **137** can be non-obliquely angled. For example, a major axis of the slot **137** can extend perpendicular to a central longitudinal axis of the fluid lumen **142B**, a central longitudinal axis of the housing **104B**, and/or a central longitudinal axis of an access device or a visualization channel of an access device. In such arrangements, the distal end of the housing **104B**, and/or the distal end of the lens **114** can likewise extend perpendicular to the central longitudinal axis of the fluid lumen **142B**, the central longitudinal axis of the housing **104B**, and/or the central longitudinal axis of an access device or a visualization channel of an access device. The slot **137** can have an angle that matches that of the lens surface.

(164) The housing can include a wiper, brush, flap, or other feature for clearing debris from the lens. The wiper can be disposed within, inserted through, and/or deployable from a lumen of the housing. For example, the wiper can be selectively deployable through a nozzle opening of a fluid lumen of the housing. The wiper can be deployed from the opening to wipe debris from the lens before, during, or after a fluid is directed through the lumen and towards the lens. FIG. **25C** illustrates an exemplary housing **104H** that can be used with the camera modules and/or access devices described herein. The housing **104H** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104H** can include one or more fluid lumens **142H**. The fluid lumen **142H** can include a nozzle **184H** disposed at a distal end thereof. The nozzle **184H** can be configured to aim or direct the flow of fluid and/or suction forces towards the lens **114** of the camera module **102**. The nozzle **184H** can be defined by a slot or cut-out **137H** formed in the sidewall of a length of tubing that protrudes distally from the distal end of the housing **104H**. The slot **137H** can allow fluid to flow between an interior of the lumen **142H** and a region adjacent to the distal end of a visualization channel, or a lens **114** or other component of a camera module **102** disposed therein. A wiper, brush, flap, or other feature **177** for clearing debris from the lens can be disposed within the lumen **142H**. The wiper **177** can include a proximal shaft **179** and a distal wiper tip **181**. The wiper tip **181** can be selectively deployable through the nozzle slot **137H** to wipe debris from the lens **114**. For example, the shaft **179** can be advanced distally within the lumen **142H** to push the wiper tip **181** out of the slot **137H** and towards the lens **114**. The wiper tip **181** can be formed from a resilient material, a shape-memory material, or can otherwise be biased towards the lens **114** to facilitate such deployment. The wiper tip **181** can be flexible. Once the wiper tip **181** is deployed through the slot **137H**, the shaft **179** can be rotated axially relative to the housing **104H** to drag the wiper tip **181** across the lens surface, clearing debris therefrom. The shaft **179** can be withdrawn proximally relative to the housing **104H** to retract the wiper tip **181** into the lumen **142H**.

(165) The housing can include various features for retracting, shielding, or manipulating tissue adjacent to the camera lens. For example, FIGS. **26A-26B** illustrate an exemplary housing **104C** that can be used with the camera modules and/or access devices described herein. The housing **104C** can include any of the features of the other housings described herein, e.g., the housing **104**. The housing **104C** can include a shield **139** that extends or protrudes distally from the distal end surface of the housing. The shield **139** can include an outer surface **139o** and an inner surface **139i**. The outer surface **139o** of the shield **139** can bear against adjacent tissue when the housing **104C** is inserted into a patient to hold the tissue back and prevent it from bulging into the field of view of the camera lens **114**. Alternatively, or in addition, as the housing **104C** is advanced distally into the patient, the distal tip of the shield **139** can gently push tissue out of the way, or can serve as a stand-off to prevent inadvertent contact between the lens **114** and the tissue, which could lead to undesirable fouling of the lens. The shield **139** can also aid in the flow of cleaning fluids or agents as they jet past the lens surface, for example by concentrating, steering, or targeting the fluid towards the lens **114**. The shield **139** can extend around an entire periphery of the housing **104C** or, as shown, can extend around only a portion of the housing periphery. The outer surface **139o** of the shield **139** can have a profile that matches that of the outer surface **136o** of the housing **104C**, such

that the housing and the shield define a continuous smooth outer surface. The shield **139** can have a convex outer surface and a concave inner surface. The shield **139** can have a crescent-shaped transverse cross section. The shield **139** can include fillets or chamfers **141** at the lateral edges thereof to provide a smooth transition to the distal-facing surface of the housing **104C**. The inner surface of the shield **139** can have a radius of curvature that follows that of the lens **114**. The shield **139** can protrude distally from the distal end surface of the housing **104C** by a distance D. The distance D can be in the range of about 2 mm to about 30 mm. The distance D can be in the range of about 4 mm to about 12 mm. The distance D can be about 8 mm.

(166) The shield can be movable with respect to the housing. For example, the shield can be retractable relative to the housing, e.g., longitudinally retractable. In some embodiments, the shield can be slidably disposed within a lumen formed in the housing. The shield can be configured to translate longitudinally within the lumen in a proximal-distal direction. This can allow the shield to be selectively deployed or retracted as desired by the user, or for the degree of shield protrusion to be adjusted during the surgery. Movement of the shield relative to the housing can be controlled in various ways, for example by the user manually grasping a proximal end of the shield and sliding it relative to the housing. FIG. **26C** illustrates an exemplary housing **104D** that can be used with the camera modules and/or access devices described herein. The housing **104D** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104D** can include a lumen **143** in which the shield **139** is slidably mounted, thereby facilitating longitudinal adjustment of the shield relative to the housing **104D**.

(167) The shield can include a wiper, brush, flap, fluid jet, vacuum port, or other feature for clearing debris from the lens, for example, as the shield is moved relative to the housing. FIG. **26D** illustrates an exemplary housing **104E** that can be used with the camera modules and/or access devices described herein. The housing **104E** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104E** can include a lumen **143** in which the shield **139** is slidably mounted, thereby facilitating longitudinal adjustment of the shield relative to the housing **104E**. The shield **139** can include a wiper flap **145** mounted to the inner surface **139i** of the shield. As the shield **139** is withdrawn proximally relative to the housing **104E**, the flap **145** can contact the distal end of the housing, causing the flap to splay outward and wipe across the face of the lens **114**. Continued proximal movement of the shield **139** can cause the flap **145** to fold over onto itself and to slide up into the lumen **143**. When the shield **139** is advanced distally relative to the housing **104E**, the flap **145** can lie flat against the inner sidewall **139i** of the shield so as not to block the view of the camera lens **114**. The flap **145** can be formed from a flexible and/or resilient material, such as an elastomer, silicone, or the like.

(168) The tissue shield can be disposed within a lumen of the housing as described above, or can be otherwise incorporated into the system. For example, the tissue shield can be formed integrally with the housing, can be formed integrally with the access device, and/or can be formed integrally with the camera module. As another example, the tissue shield can be slidably disposed within a lumen of the housing, a lumen of the access device, and/or a lumen of the camera module. As yet another example, the tissue shield can be slidable along an exterior surface of the housing, the access device, and/or the camera module.

(169) The system can include active mechanical and/or acoustic systems for maintaining clear visualization for the camera. For example, the system can include an ultrasonic agitator that can be actuated to clear debris from the lens or to prevent debris from blocking the lens in the first place. FIG. **27A** illustrates an exemplary camera module **102B** that can be used with the housings and/or access devices described herein. The camera module **102B** can include any of the features of the other camera modules described herein, e.g., the camera module **102**. As shown, the camera module **102B** can include an ultrasound transducer **147**. The transducer **147** can be mounted to the lens barrel **124** as shown, or to any other component of the camera module, such as the lens **114**, image sensor **112**, illumination lumen **128**, PCBA **120**, etc. While the transducer **147** is shown

mounted to the camera module **102B**, it will be appreciated that the transducer can be mounted to any component of the visualization system, including the housing or the access device. The transducer can also be disposed in or on a separate component, such as an outer sheath or collar disposed around the camera module or access port. The transducer can be operably connected to the controller **106** via electrical wires disposed in the connector **108**. In use, an electric potential can be applied to the transducer to generate a mechanical vibration that can shake debris away from or off of the lens.

(170) The transducer can be a piezoelectric transducer. The transducer can emit ultrasonic waves, e.g., in a frequency in the range of about 20 kHz to about 40 kHz. The transducer can be a ring-shaped transducer, a plate-type transducer, or any other suitable transducer type.

(171) FIG. **27B** illustrates an exemplary camera module **102C** that can be used with the housings and/or access devices described herein. The camera module **102C** can include any of the features of the other camera modules described herein, e.g., the camera module **102**. As shown, the camera module **102C** can include an ultrasound transducer **147**. The transducer **147** can be in the form of an annular or ring-shaped element axially disposed between the distal end of the lens barrel **124** and a transparent cap **149**. The cap **149** can form the outermost distal extent of the camera module **102C**, and thus can define a surface that is exposed to the surgical environment where debris could potentially accumulate. The transducer **147** can be a piezo element that oscillates in the direction of the illustrated arrows when an electric potential is applied thereto. This can be effective to vibrate the cap **149** and encourage droplets or debris **151** to leave the cap surface. The annular shape of the transducer **147** can advantageously provide a clear line of site through the transducer to the lens **114** or image sensor **112** while applying substantially uniform vibration around the entire circumference of the cap **149**.

(172) While ultrasonic agitators are described above, it will be appreciated that any means for applying vibration or agitation to the system can be used instead or in addition. In some embodiments, an electric motor having an eccentrically mounted mass can be used to apply vibration to the system. The motor can be mounted within the camera module, housing, or access device. In some embodiments, the system can include an actuator, such as a solenoid or linear actuator, configured to strike the camera module when an electric potential is applied thereto. In use, current can be selectively applied to the actuator to cause the actuator to strike the camera module and thereby dislodge or clear debris from the lens. The actuator can be mounted within the camera module, housing, or access device. In some embodiments, a generator that operates below the ultrasound frequency range, e.g., in the infrasound or acoustic ranges, can be used to clear debris from the lens.

(173) The system can include a membrane movable across the lens to maintain visibility through the lens. The membrane can be transparent. The membrane can be drawn across the lens to change the portion of the membrane that is aligned with the lens, e.g., to move a soiled section of the membrane away from the lens and to replace it with a clean section of the membrane. The membrane can be a continuous loop of material that is drawn across the lens and moved past a wiper, brush, flap, fluid jet, vacuum port, or other cleaning element that removes debris from the membrane. Thus, a soiled section of the membrane can be moved away from the lens and replaced with a clean section of the membrane, the soiled section eventually being moved across a brush or wiper to clean that section before it is again aligned with the lens. The membrane can be wound around one or more spools, for example with soiled sections of the membrane being wound around one spool after use as clean sections are unwound from another spool to be aligned with the lens. Movement of the membrane can be continuous or intermittent. Movement of the membrane can be controlled by an electric motor, a manual crank or handle, or various other mechanisms. Movement of the membrane can occur automatically, e.g., in response to the controller detecting debris or lack of clarity in images captured from the camera, or manually, e.g., in response to user actuation of a button, wheel, or other input mechanism.

(174) FIG. 28A illustrates an exemplary housing **104F** that can be used with the camera modules and/or access devices described herein. The housing **104F** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104F** can include a movable membrane **153**. A first end of the membrane **153** can be wound around a first “clean” spool **155A** disposed at or near a proximal end of the housing **104F**. The membrane **153** can extend through a first longitudinal lumen **157A** of the housing **104F**, across the exposed face of the lens **114**, and back through a second longitudinal lumen **157B** of the housing. A second end of the membrane **153** can be wound around a second “soiled” spool **155B** disposed at or near the proximal end of the housing **104F**. In use, one or both spools **155** can be rotated to move the membrane **153** in the direction of the indicated arrows, thereby moving a soiled section of the membrane away from the lens **114** and instead aligning a clean section of the membrane with the lens. One or both of the spools **155** can be driven by a motor or manual input device.

(175) FIG. 28B illustrates an exemplary housing **104G** that can be used with the camera modules and/or access devices described herein. The housing **104G** can include any of the features of the other housings described herein, e.g., the housing **104**. As shown, the housing **104G** can include a movable membrane **153**. The membrane **153** can be a continuous loop of material that follows a path through the housing **104G** that brings the membrane across the exposed face of the lens **114** and across a wiper, brush, flap, fluid jet, vacuum port, or other cleaning element **159**. The membrane **153** can be wrapped around a series of rollers **161**, one or more of which can be coupled to a motor or manual input device to effect movement of the membrane. In use, one or more of the rollers **161** can be rotated to move the membrane **153** in the direction of the indicated arrows, thereby moving a soiled section of the membrane away from the lens **114** and instead aligning a clean section of the membrane with the lens. As the membrane **153** is moved, the soiled section of the membrane can be carried across the cleaning element **159** to clean that portion of the membrane before it is realigned with the lens **114**.

(176) The system can include a mechanical wiper movable across the lens to clear debris therefrom. FIGS. 29A-29D illustrate an exemplary wiper **163**. The wiper **163** can be inserted through or disposed within the working channel of any of the access devices described herein, e.g., a working channel **174B** of an access device **110B** as shown. The wiper **163** can be moved in a proximal-distal direction, e.g., by applying a manual input force to a proximal end of the wiper, to cause the wiper to move in a transverse direction across the camera lens **114** to clear debris therefrom. As shown, the wiper **163** can include an elongate wiper shaft **165** and a wiper tip **167**. The tip **167** can be formed from a relatively soft material such as silicone, rubber, elastomers, etc. The shaft **165** can include an offset or jog **169** that interacts with a protrusion **171** formed in the working channel of the access device to convert longitudinal movement of the shaft into lateral movement of the wiper tip **167**. In particular, as shown in FIG. 29A and FIG. 29C, when the wiper shaft **165** is moved proximally within the working channel, the protrusion **171** contacts the offset **169** in the wiper shaft to urge the wiper tip **167** laterally (to the right in the illustrated example). The protrusion **171** and/or the offset **169** can define ramped or tapered surfaces to encourage such lateral movement. Lateral movement of the wiper tip **167** across the lens **114** can be effective to clear debris from the lens surface. As shown in FIG. 29B and FIG. 29D, when the wiper shaft **165** is subsequently moved distally, the offset **169** in the wiper shaft can be moved longitudinally past the protrusion **171**, such that the wiper shaft is allowed to move in the opposite lateral direction, carrying the wiper tip **167** back across the lens **114** in the opposite direction (to the left in the illustrated example). The wiper shaft **165** can be biased towards the sidewall of the working channel (to the left in the illustrated example) to encourage such lateral movement. Return lateral movement of the wiper tip **167** across the lens **114** can be effective to further clear debris from the lens.

(177) FIGS. 30A-30B illustrate another exemplary wiper **173**. The wiper **173** can be inserted through or disposed within the working channel of any of the access devices described herein. The

wiper 173 can include a flexible and/or resilient flap of material 175 that is biased towards the visualization lumen 176 of the access device 110. As the camera module 102 and/or housing 104 is moved longitudinally past the flap 175, the flap can wipe across the exposed face of the lens 114 to clear debris therefrom. In particular, as shown in FIG. 30A, when the housing 104 and camera module 102 are withdrawn proximally, the bias of the wiper 173 can cause the flap 175 to move into the visualization channel 176 of the access device 110. As shown in FIG. 30B, as the housing 104 and camera module 102 are subsequently advanced distally, the flap 175 can wipe across the exposed surface of the lens 114 as the wiper 173 is pushed out of the way by the housing and camera module. The wiper 173 can thus effect automatic cleaning of the lens 114 each time the camera module 102 is moved past the wiper flap 175. The camera module 102 can be repeatedly moved up and down within the access device 110 as many times as needed or desired to clean the lens 114. The wiper flap 175 can be formed from a relatively soft material such as silicone, rubber, elastomers, etc.

(178) Various lens cleaning mechanisms described herein can be used individually or in combination. For example, a visualization system can include a mechanical wiper, an ultrasound agitator, a movable membrane, and a fluid cleaning system. As another example, a visualization system can include an ultrasound agitator and a fluid cleaning system. As another example, a visualization system can include a movable membrane and a fluid cleaning system. Any other combination or sub-combination can also be used.

(179) The visualization systems and/or access devices disclosed herein can be used in any of a variety of surgical procedures. For example, such systems and devices can be used in ear, nose, and throat (ENT) surgery, sinus surgery, gastrointestinal (GI) surgery, abdominal surgery, intravascular surgery, cardiothoracic surgery, joint surgery, and so forth. In some embodiments, the visualization system can be used, with or without an access device, as a self-cleaning endoscope for sinus surgery. Active and/or passive cleaning features of the system can reduce or eliminate the need to repeatedly withdraw the scope from the patient to clean the lens. In some embodiments, the visualization system can be used, with or without an access device, as a self-cleaning endoscope for airway surgery (e.g., laryngoscopy, bronchoscopy, etc.). In some embodiments, the visualization system can be used, with or without an access device, as a self-cleaning upper and/or lower GI scope. The visualization system can form a rigid endoscope with self-cleaning abilities.

(180) The various housings and camera modules disclosed herein can be used with an access device, or can be used independently without any access device. Any of the systems described herein can include a housing that is separate and distinct from the camera module, or can include an integral camera module and housing, e.g., a system in which the outer envelope of the camera module defines the housing.

(181) It should be noted that any ordering of method steps expressed or implied in the description above or in the accompanying drawings is not to be construed as limiting the disclosed methods to performing the steps in that order. Rather, the various steps of each of the methods disclosed herein can be performed in any of a variety of sequences. In addition, as the described methods are merely exemplary embodiments, various other methods that include additional steps or include fewer steps are also within the scope of the present disclosure.

(182) The devices disclosed herein can be constructed from any of a variety of known materials. Exemplary materials include those which are suitable for use in surgical applications, including metals such as stainless steel, titanium, nickel, cobalt-chromium, or alloys and combinations thereof, polymers such as PEEK, ceramics, carbon fiber, and so forth. The various components of the devices disclosed herein can be rigid or flexible. One or more components or portions of the device can be formed from a radiopaque material to facilitate visualization under fluoroscopy and other imaging techniques, or from a radiolucent material so as not to interfere with visualization of other structures. Exemplary radiolucent materials include carbon fiber and high-strength polymers.

(183) The devices and methods disclosed herein can be used in minimally-invasive surgery and/or

open surgery. While the devices and methods disclosed herein are generally described in the context of spinal surgery on a human patient, it will be appreciated that the methods and devices disclosed herein can be used in any type of surgery on a human or animal subject, in non-surgical applications, on non-living objects, and so forth.

(184) Although specific embodiments are described above, it should be understood that numerous changes may be made within the spirit and scope of the concepts described.

## Claims

1. A surgical visualization system, comprising: a camera module; a housing into which the camera module is mounted, the housing extending between a proximal-facing end surface and a distal-facing end surface, the housing comprising an outer sidewall having a concave surface extending between the proximal-facing end surface and the distal-facing end surface and a convex surface disposed opposite the concave surface and extending distally from the proximal-facing end surface, wherein the concave surface is connected to the convex surface by first and second transition regions that define sections of respective cylinders, a camera lumen extending through the housing in which the camera module is disposed, and first and second fluid lumens extending through the housing wherein the first and second transition regions follow the outer perimeters of the first and second fluid lumens; and wherein the housing includes a tissue shield that extends in a distal direction from the distal-facing surface, the tissue shield having a crescent-shaped transverse cross section.
  2. The system of claim 1, further comprising: an active lens cleaning device configured to remove debris from a lens of the camera module, the active lens cleaning device comprising a nozzle that extends from the distal-facing end surface of the housing, the nozzle including an opening configured to direct fluid from at least one of the first and second fluid lumens across the distal-facing end surface towards the lens and away from the nozzle; wherein the opening is configured to direct fluid towards the lens at an oblique angle with respect to a central longitudinal axis of the housing; and wherein a distal-most termination of the tissue shield extends beyond the nozzle with respect to the central longitudinal axis.
  3. The system of claim 2, wherein the active lens cleaning device comprises a source of positive pressure gas directed towards the lens through a lumen of the housing.
  4. The system of claim 2, wherein the opening is located between opposite lateral ends of the tissue shield.
  5. The system of claim 2, wherein the tissue shield includes the nozzle.
  6. The system of claim 1, wherein the camera module comprises an image sensor and a lens configured to direct reflected light onto the image sensor, the image sensor and the lens being disposed within the housing.
  7. The system of claim 6, wherein a central region of the lens is coated with hydrophobic coating and a peripheral region of the lens is coated with a hydrophilic coating.
  8. The system of claim 1, wherein the tissue shield extends around less than an entire periphery of the housing.
  9. The system of claim 8, wherein the tissue shield defines a curved inner surface.
  10. The system of claim 9, wherein the tissue shield defines an outer surface with a profile that matches that of an outer surface of the housing.
  11. The system of claim 1, wherein lateral edges of the tissue shield define chamfers that provide a smooth transition to the distal-facing surface of the housing.
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