

[0046] FIG. 9A is a functional block diagram of an integrated cancer imaging, screening, and biopsy system, with optical therapy delivery and monitoring capabilities in accord with the present invention;

[0047] FIG. 9B is a functional block diagram of an integrated tumor imaging and diagnostic system, with stereograph surgical support and display capabilities in accord with the present invention;

[0048] FIG. 10 is a side elevational view of the distal end of an optical fiber having an inflatable balloon for anchoring the optical fiber in place adjacent to a treatment site;

[0049] FIGS. 11A, 11B, and 11C illustrate an embodiment of an optical fiber that does not include any imaging lens between the distal end of the optical fiber and an ROI; and

[0050] FIG. 12 is a cross-sectional view of an embodiment of the present invention that is incorporated into a rigid endoscope.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0051] Prior Art Imaging Endoscopes

[0052] With reference to FIG. 1A, the distal end of a flexible endoscope 20 is illustrated schematically, indicating how a non-scanning imaging process is implemented. Imaging lenses 22a and 22b receive light reflected from an ROI within a patient's body illuminated with light sources 24a and 24b. Although shown adjacent imaging lens 22b, these light sources may alternatively be disposed external to the patient's body so that light produced by the sources is conveyed through optical fibers (not shown) to the internal site. Light that has passed through imaging lenses 22a and 22b is received by a pixel array optical fiber bundle 30 (or alternatively by a pixel array camera—not shown). In this case, each camera or detector disposed at the distal end within a patient's body, or proximally at the end of the fiber optic bundle through which the light from imaging lenses 22a and 22b is conveyed outside the patient's body, corresponds to only a single image pixel. As noted above, the size of the optical fibers or of the array required for producing an overall image of the diffusely illuminated ROI is limited by the diameter of endoscope 20.

[0053] A time series pixel endoscope 32, which is shown in FIG. 1B, detects each successive pixel at an image plane 33a. As before, imaging lenses 22a and 22b focus the image on image plane 33a, which is then scanned by a cantilevered optical fiber 34 so that light corresponding to each successive pixel in an image is transmitted through the cantilevered optical fiber and added to the previously transmitted image pixel data to be displayed at the proximal end of the time series pixel endoscope. Since only one or perhaps a few optical fibers are required to convey the stream of pixel light data to the proximal end of the time series pixel endoscope, the shaft of the endoscope can be made much smaller in diameter than the non-scanning design shown in FIG. 1A. Cantilevered optical fiber 32 is preferably a multi-mode type fiber, and receives the diffuse illumination provided by light sources 24a and 24b reflected from the ROI within the patient's body. It should be noted that this prior art scanning device is only used for imaging an ROI that is diffusely illuminated, as is true of virtually all conventional endoscopic illumination systems.

[0054] Scanning Devices Used in the Present Invention

[0055] In contrast to the prior art devices illustrated in FIGS. 1A and 1B, the present invention integrates both imaging and non-imaging functionality, such as diagnosis, monitoring, and therapy of an internal ROI, instead of requiring separate instruments for imaging and for rendering therapy or other functions to a site. Many optical diagnostic and therapeutic techniques rely on high quality illumination at elevated intensities, which is inherent in optical scanning and cannot be achieved with diffuse illumination. A scanned beam of intense optical energy is more effective at overcoming the signal-to-noise limitations of photon detectors used in diagnostic imaging systems. When fluorescent dye molecules are used as tracers for specific cells or structures, the signal conversion rates from illumination to fluorescence are very low and often buried in noise. In many therapeutic applications, such as PDT, the optical excitation of PDT labels on cancerous cells creates free radicals that kill nearby cells. Doses of intense optical illumination are applied to overcome the natural buffering mechanisms within the body, to attain effective concentrations of free radicals. Laser therapies that rely on optical heating, cutting, and cauterization of tissues require the highest optical intensities that can be delivered and cannot be used effectively with diffuse illumination. Directed, focused beams of light on tissue for precise exposure times are necessary for reducing surrounding tissue damage which is provided in a controlled optical scan system. Furthermore, high quality illumination can include a high degree of optical monochromaticity, coherence, polarization, high modulation frequency, high pulse repetition rates, and short pulse duration.

[0056] FIGS. 1C and 1D illustrate embodiments of two-dimensional (2D) scanning point-source illuminators. In FIG. 1C, a scanning point-source illuminator 40 in accord with the present invention is illustrated. Point-source illuminator 40 has the capability of providing a point source illumination through an optical fiber 42 that is caused to scan an ROI within a patient's body. Light emitted by the scanning optical fiber is transmitted through imaging lenses 44a, 44b, and 44c to illuminate different portions of the ROI as the point source provided by the scanning optical fiber is caused to move. In the position illustrated with solid lines, a light beam 46 illuminates a particular portion of the ROI, while in the position illustrated by dash lines, the scanning optical fiber produces light beam 46' that illuminates a different portion of the ROI. Light reflected from each successive point illuminated by the scanning optical fiber is reflected back through imaging lenses 44c, 44b, and 44a and is received by RGB photon detectors 45f, 45g, and 45b, respectively, which produce corresponding electrical signals that are transmitted outside the patient's body for use in displaying a full color image of the ROI.

[0057] In addition, therapy can be rendered using scanning optical fiber 42. For example, by illuminating the points scanned by it using a relatively high powered laser, high intensity light PDT, or thermotherapy can be applied to the ROI. Since the signals produced by the RGB photon detectors correspond to successive points in the ROI, the image resulting from the signal that they produce is based upon a time series accumulation of image pixel data. Scanning optical fiber 42 is preferably a single mode or hollow optical fiber, of telecommunications grade or better. One significant advantage of this integrated system is that the mechanisms