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(54) **QUICK-RELEASE END EFFECTORS AND RELATED SYSTEMS AND METHODS**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,870,264 A 3/1975 Robinson
3,989,952 A 11/1976 Hohmann
(Continued)

FOREIGN PATENT DOCUMENTS

CA 2690808 C 9/2016
CN 102821918 A 12/2012
(Continued)

OTHER PUBLICATIONS

Faraz et al., "Engineering Approaches to Mechanical and Robotic Design for Minimally Invasive Surgery (MIS)," Kluwer Academic Publishers (Boston), 2000, 13 pp.

(Continued)

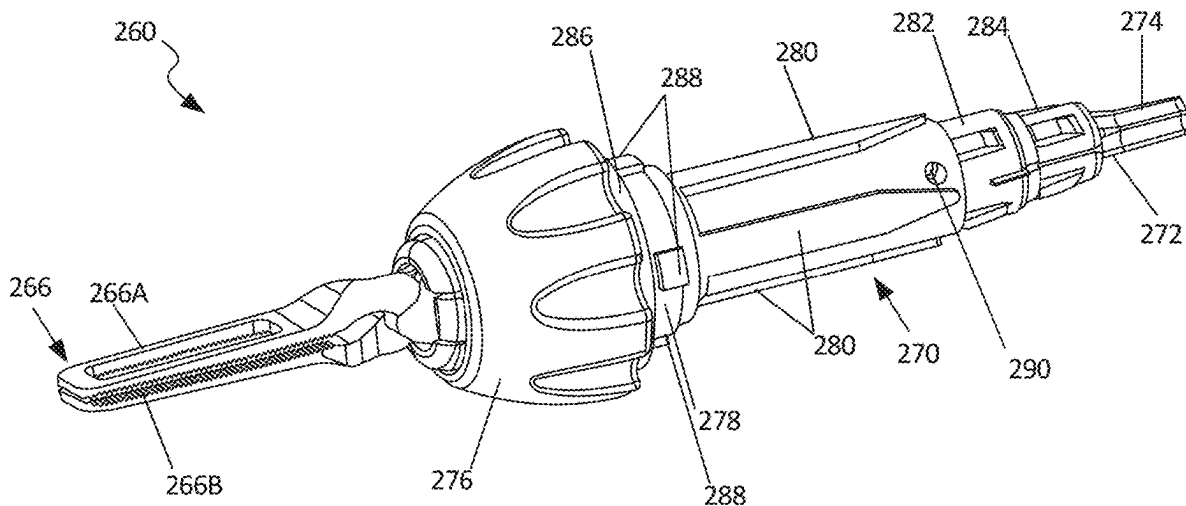
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(57) **ABSTRACT**

The various embodiments disclosed herein relate to arms or forearms of medical devices that are configured to couple with quick-release end effectors, quick-release end effectors for use with such medical devices, and arms or forearms coupled to such quick-release end effectors. Certain forearms and end effectors have magnetic couplings, while others have mechanical couplings, and further implementations have both magnetic and mechanical couplings.

20 Claims, 10 Drawing Sheets



Related U.S. Application Data					
continuation of application No. 14/853,477, filed on Sep. 14, 2015, now Pat. No. 10,342,561.		5,462,546 A	10/1995	Rydell	
		5,471,515 A	11/1995	Fossum et al.	
		5,515,478 A	5/1996	Wang	
		5,522,669 A *	6/1996	Recker	F16D 1/116 403/328
(60)	Provisional application No. 62/049,419, filed on Sep. 12, 2014.	5,524,180 A	6/1996	Wang et al.	
		5,553,198 A	9/1996	Wang et al.	
		5,562,448 A	10/1996	Mushabac	
		5,588,442 A	12/1996	Scovil et al.	
(51)	Int. Cl.	5,620,417 A	4/1997	Jang et al.	
	<i>A61B 18/14</i> (2006.01)	5,623,582 A	4/1997	Rosenberg	
	<i>A61B 34/30</i> (2016.01)	5,624,380 A	4/1997	Kaneko et al.	
	<i>A61B 17/00</i> (2006.01)	5,624,398 A	4/1997	Smith et al.	
	<i>A61B 18/00</i> (2006.01)	5,632,761 A	5/1997	Smith et al.	
	<i>A61B 90/50</i> (2016.01)	5,645,520 A	7/1997	Nakamura et al.	
		5,657,429 A	8/1997	Wang et al.	
(52)	U.S. Cl.	5,657,584 A	8/1997	Hamlin	
	CPC <i>A61B 18/1445</i> (2013.01); <i>A61B 34/30</i> (2016.02); <i>A61B 2017/00398</i> (2013.01); <i>A61B 2017/00473</i> (2013.01); <i>A61B 2017/00477</i> (2013.01); <i>A61B 2017/00876</i> (2013.01); <i>A61B 2018/00172</i> (2013.01); <i>A61B 2018/00208</i> (2013.01); <i>A61B 2018/00595</i> (2013.01); <i>A61B 90/50</i> (2016.02)	5,672,168 A	9/1997	De La Torre et al.	
		5,674,030 A	10/1997	Sigel	
		5,728,599 A	3/1998	Rostoker et al.	
		5,736,821 A	4/1998	Suyama	
		5,754,741 A	5/1998	Wang et al.	
		5,762,458 A	6/1998	Wang et al.	
		5,769,640 A	6/1998	Jacobus et al.	
		5,791,231 A	8/1998	Cohn et al.	
		5,792,135 A	8/1998	Madhani et al.	
		5,797,538 A	8/1998	Heaton et al.	
(58)	Field of Classification Search	5,797,900 A	8/1998	Madhani et al.	
	CPC <i>A61B 2017/00398</i> ; <i>A61B 2017/00464</i> ; <i>A61B 2017/00473</i> ; <i>A61B 2017/00477</i> ; <i>A61B 90/50</i> ; <i>A61B 2018/00208</i>	5,807,377 A	9/1998	Madhani et al.	
	See application file for complete search history.	5,808,665 A	9/1998	Green	
		5,815,640 A	9/1998	Wang et al.	
		5,825,982 A	10/1998	Wright et al.	
		5,841,950 A	11/1998	Wang et al.	
(56)	References Cited	5,845,646 A	12/1998	Lemelson	
	U.S. PATENT DOCUMENTS	5,855,583 A	1/1999	Wang et al.	
		5,876,325 A	3/1999	Mizuno et al.	
		5,878,193 A	3/1999	Wang et al.	
		5,878,783 A	3/1999	Smart	
		5,895,417 A	4/1999	Pomeranz et al.	
		5,906,591 A	5/1999	Dario et al.	
		5,907,664 A	5/1999	Wang et al.	
		5,910,129 A	6/1999	Koblish et al.	
		5,911,036 A	6/1999	Wright et al.	
		5,913,874 A *	6/1999	Berns	A61B 17/295 606/205
		4,246,661 A	1/1981	Pinson	
		4,258,716 A	3/1981	Sutherland	
		4,278,077 A	7/1981	Mizumoto	
		4,538,594 A	9/1985	Boebel et al.	
		4,568,311 A	2/1986	Miyake	
		4,579,476 A *	4/1986	Post	F16D 3/387 403/322.2
		4,623,183 A	11/1986	Aomori	
		4,736,645 A	4/1988	Zimmer	
		4,771,652 A	9/1988	Zimmer	
		4,852,391 A	8/1989	Ruch et al.	
		4,896,015 A	1/1990	Taboada et al.	
		4,897,014 A	1/1990	Tietze	
		4,922,755 A	5/1990	Oshiro et al.	
		4,922,782 A	5/1990	Kawai	
		4,990,050 A	2/1991	Tsuge et al.	
		5,019,968 A	5/1991	Wang et al.	
		5,108,140 A	4/1992	Bartholet	
		5,172,639 A	12/1992	Wiesman et al.	
		5,176,649 A	1/1993	Wakabayashi	
		5,178,032 A	1/1993	Zona et al.	
		5,187,032 A	2/1993	Sasaki et al.	
		5,187,796 A	2/1993	Wang et al.	
		5,195,388 A	3/1993	Zona et al.	
		5,201,325 A	4/1993	McEwen et al.	
		5,217,003 A	6/1993	Wilk	
		5,263,382 A	11/1993	Brooks et al.	
		5,271,384 A	12/1993	McEwen et al.	
		5,284,096 A	2/1994	Pelrine et al.	
		5,297,443 A	3/1994	Wentz	
		5,297,536 A	3/1994	Wilk	
		5,304,899 A	4/1994	Sasaki et al.	
		5,307,447 A	4/1994	Asano et al.	
		5,353,807 A	10/1994	Demarco	
		5,363,935 A	11/1994	Schempf et al.	
		5,382,885 A	1/1995	Salcudean et al.	
		5,388,528 A	2/1995	Pelrine et al.	
		5,436,542 A	7/1995	Petelin et al.	
		5,441,494 A	8/1995	Ortiz	
		5,458,131 A	10/1995	Wilk	
		5,458,583 A	10/1995	Mcneely et al.	
		5,458,598 A	10/1995	Feinberg et al.	
		5,971,976 A	10/1999	Wang et al.	
		5,993,467 A	11/1999	Yoon	
		6,001,108 A	12/1999	Wang et al.	
		6,007,550 A	12/1999	Wang et al.	
		6,030,365 A	2/2000	Laufer	
		6,031,371 A	2/2000	Smart	
		6,058,323 A	5/2000	Lemelson	
		6,063,095 A	5/2000	Wang et al.	
		6,066,090 A	5/2000	Yoon	
		6,086,529 A	7/2000	Arndt	
		6,102,850 A	8/2000	Wang et al.	
		6,107,795 A	8/2000	Smart	
		6,113,596 A	9/2000	Hooven et al.	
		6,132,368 A	10/2000	Cooper	
		6,132,441 A	10/2000	Grace	
		6,139,563 A	10/2000	Cosgrove et al.	
		6,156,006 A	12/2000	Brosens et al.	
		6,159,146 A	12/2000	El Gazayerli	
		6,162,171 A	12/2000	Ng et al.	
		D438,617 S	3/2001	Cooper et al.	
		6,206,903 B1	3/2001	Ramans	
		D441,076 S	4/2001	Cooper et al.	
		6,223,100 B1	4/2001	Green	
		D441,862 S	5/2001	Cooper et al.	
		6,238,415 B1	5/2001	Sepetka et al.	
		6,240,312 B1	5/2001	Alfano et al.	
		6,241,730 B1	6/2001	Alby	
		6,244,809 B1	6/2001	Wang et al.	
		6,246,200 B1	6/2001	Blumenkranz et al.	
		D444,555 S	7/2001	Cooper et al.	
		6,286,514 B1	9/2001	Lemelson	
		6,292,678 B1	9/2001	Hall et al.	
		6,293,282 B1	9/2001	Lemelson	
		6,296,635 B1	10/2001	Smith et al.	

(56)

References Cited

U.S. PATENT DOCUMENTS

6,309,397 B1	10/2001	Julian et al.	6,774,597 B1	8/2004	Borenstein
6,309,403 B1	10/2001	Minor et al.	6,776,165 B2	8/2004	Jin
6,312,435 B1	11/2001	Wallace et al.	6,780,184 B2	8/2004	Tanrisever
6,321,106 B1	11/2001	Lemelson	6,783,524 B2	8/2004	Anderson et al.
6,327,492 B1	12/2001	Lemelson	6,785,593 B2	8/2004	Wang et al.
6,331,181 B1	12/2001	Tierney et al.	6,788,018 B1	9/2004	Blumenkranz
6,346,072 B1	2/2002	Cooper	6,792,663 B2	9/2004	Krzyzanowski
6,352,503 B1	3/2002	Matsui et al.	6,793,653 B2	9/2004	Sanchez et al.
6,364,888 B1	4/2002	Niemeyer et al.	6,799,065 B1	9/2004	Niemeyer
6,371,952 B1	4/2002	Madhani et al.	6,799,088 B2	9/2004	Wang et al.
6,394,998 B1	5/2002	Wallace et al.	6,801,325 B2	10/2004	Farr et al.
6,398,726 B1	6/2002	Ramans et al.	6,804,581 B2	10/2004	Wang et al.
6,400,980 B1	6/2002	Lemelson	6,810,281 B2	10/2004	Brock et al.
6,408,224 B1	6/2002	Okamoto et al.	6,817,972 B2	11/2004	Snow
6,424,885 B1	7/2002	Niemeyer et al.	6,817,974 B2	11/2004	Cooper et al.
6,432,112 B2	8/2002	Brock et al.	6,817,975 B1	11/2004	Farr et al.
6,436,107 B1	8/2002	Wang et al.	6,820,653 B1	11/2004	Schempf et al.
6,441,577 B2	8/2002	Blumenkranz et al.	6,824,508 B2	11/2004	Kim et al.
6,450,104 B1	9/2002	Grant et al.	6,824,510 B2	11/2004	Kim et al.
6,451,027 B1	9/2002	Cooper et al.	6,832,988 B2	12/2004	Sproul
6,454,758 B1	9/2002	Thompson et al.	6,832,996 B2	12/2004	Woloszko et al.
6,459,926 B1	10/2002	Nowlin et al.	6,836,703 B2	12/2004	Wang et al.
6,463,361 B1	10/2002	Wang et al.	6,837,846 B2	1/2005	Jaffe et al.
6,468,203 B2	10/2002	Belson	6,837,883 B2	1/2005	Moll et al.
6,468,265 B1	10/2002	Evans et al.	6,839,612 B2	1/2005	Sanchez et al.
6,470,236 B2	10/2002	Ohtsuki	6,840,938 B1	1/2005	Morley et al.
6,478,681 B1	11/2002	Overaker et al.	6,852,107 B2	2/2005	Wang et al.
6,491,691 B1	12/2002	Morley et al.	6,858,003 B2	2/2005	Evans et al.
6,491,701 B2	12/2002	Tierney et al.	6,860,346 B2	3/2005	Burt et al.
6,493,608 B1	12/2002	Niemeyer	6,860,877 B1	3/2005	Sanchez et al.
6,496,099 B2	12/2002	Wang et al.	6,866,671 B2	3/2005	Tierney et al.
6,497,651 B1	12/2002	Kan et al.	6,870,343 B2	3/2005	Borenstein et al.
6,508,413 B2	1/2003	Bauer et al.	6,871,117 B2	3/2005	Wang et al.
6,512,345 B2	1/2003	Borenstein et al.	6,871,563 B2	3/2005	Choset et al.
6,522,906 B1	2/2003	Salisbury et al.	6,879,880 B2	4/2005	Nowlin et al.
6,544,276 B1	4/2003	Azizi	6,892,112 B2	5/2005	Wang et al.
6,548,982 B1	4/2003	Papanikolopoulos et al.	6,899,705 B2	5/2005	Niemeyer
6,554,790 B1	4/2003	Moll	6,902,560 B1	6/2005	Morley et al.
6,565,554 B1	5/2003	Niemeyer	6,905,460 B2	6/2005	Wang et al.
6,574,355 B2	6/2003	Green	6,905,491 B1	6/2005	Wang et al.
6,587,750 B2	7/2003	Gerbi et al.	6,911,916 B1	6/2005	Wang et al.
6,591,239 B1	7/2003	Mccall et al.	6,917,176 B2	7/2005	Schempf et al.
6,594,552 B1	7/2003	Nowlin et al.	6,933,695 B2	8/2005	Blumenkranz
6,610,007 B2	8/2003	Belson et al.	6,936,001 B1	8/2005	Snow
6,620,173 B2	9/2003	Gerbi et al.	6,936,003 B2	8/2005	Iddan
6,642,836 B1	11/2003	Wang et al.	6,936,042 B2	8/2005	Wallace et al.
6,645,196 B1	11/2003	Nixon et al.	6,943,663 B2	9/2005	Wang et al.
6,646,541 B1	11/2003	Wang et al.	6,949,096 B2	9/2005	Davison et al.
6,648,814 B2	11/2003	Kim et al.	6,951,535 B2	10/2005	Ghodoussi et al.
6,659,939 B2	12/2003	Moll et al.	6,965,812 B2	11/2005	Wang et al.
6,661,571 B1	12/2003	Shioda et al.	6,974,411 B2	12/2005	Belson
6,671,581 B2	12/2003	Niemeyer et al.	6,974,449 B2	12/2005	Niemeyer
6,676,684 B1	1/2004	Morley et al.	6,979,423 B2	12/2005	Moll
6,684,129 B2	1/2004	Salisbury et al.	6,984,203 B2	1/2006	Tartaglia et al.
6,685,648 B2	2/2004	Flaherty et al.	6,984,205 B2	1/2006	Gazdzinski
6,685,698 B2	2/2004	Morley et al.	6,991,627 B2	1/2006	Madhani et al.
6,687,571 B1	2/2004	Byrne et al.	6,993,413 B2	1/2006	Sunaoshi
6,692,485 B1	2/2004	Brock et al.	6,994,703 B2	2/2006	Wang et al.
6,699,177 B1	3/2004	Wang et al.	6,994,708 B2	2/2006	Manzo
6,699,235 B2	3/2004	Wallace et al.	6,997,908 B2	2/2006	Carrillo, Jr. et al.
6,702,734 B2	3/2004	Kim et al.	7,025,064 B2	4/2006	Wang et al.
6,702,805 B1	3/2004	Stuart	7,027,892 B2	4/2006	Wang et al.
6,714,839 B2	3/2004	Salisbury et al.	7,033,344 B2	4/2006	Imran
6,714,841 B1	3/2004	Wright et al.	7,039,453 B2	5/2006	Mullick et al.
6,719,684 B2	4/2004	Kim et al.	7,042,184 B2	5/2006	Oleynikov et al.
6,720,988 B1	4/2004	Gere et al.	7,048,745 B2	5/2006	Tierney et al.
6,726,699 B1	4/2004	Wright et al.	7,053,752 B2	5/2006	Wang et al.
6,728,599 B2	4/2004	Wang et al.	7,063,682 B1	6/2006	Whayne et al.
6,730,021 B2	5/2004	Vassiliades et al.	7,066,879 B2	6/2006	Fowler et al.
6,731,988 B1	5/2004	Green	7,066,926 B2	6/2006	Wallace et al.
6,746,443 B1	6/2004	Morley et al.	7,074,179 B2	7/2006	Wang et al.
6,764,441 B2	7/2004	Chiel et al.	7,077,446 B2	7/2006	Kameda et al.
6,764,445 B2	7/2004	Ramans et al.	7,083,571 B2	8/2006	Wang et al.
6,766,204 B2	7/2004	Niemeyer et al.	7,083,615 B2	8/2006	Peterson et al.
6,770,081 B1	8/2004	Cooper et al.	7,087,049 B2	8/2006	Nowlin et al.
			7,090,683 B2	8/2006	Brock et al.
			7,097,640 B2	8/2006	Wang et al.
			7,105,000 B2	9/2006	Mcbrayer
			7,107,090 B2	9/2006	Salisbury, Jr. et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,109,678 B2	9/2006	Kraus et al.	10,702,347 B2	7/2020	Farritor et al.
7,118,582 B1	10/2006	Wang et al.	10,722,319 B2	7/2020	Farritor et al.
7,121,781 B2	10/2006	Sanchez	10,751,136 B2	8/2020	Farritor et al.
7,125,403 B2	10/2006	Julian et al.	10,806,538 B2	10/2020	Farritor et al.
7,126,303 B2	10/2006	Farritor et al.	10,966,700 B2	4/2021	Farritor et al.
7,147,650 B2	12/2006	Lee	11,013,564 B2	5/2021	Palmowski et al.
7,155,315 B2	12/2006	Niemeyer et al.	11,065,050 B2	7/2021	Farritor et al.
7,169,141 B2	1/2007	Brock et al.	11,166,758 B2	11/2021	Mohr et al.
7,182,025 B2	2/2007	Ghorbel et al.	2001/0018591 A1	8/2001	Brock et al.
7,182,089 B2	2/2007	Ries	2001/0049497 A1	12/2001	Kalloo et al.
7,199,545 B2	4/2007	Oleynikov et al.	2002/0003173 A1	1/2002	Bauer et al.
7,206,626 B2	4/2007	Quaid	2002/0013601 A1	1/2002	Nobles et al.
7,206,627 B2	4/2007	Abovitz et al.	2002/0026186 A1	2/2002	Woloszko et al.
7,210,364 B2	5/2007	Ghorbel et al.	2002/0038077 A1	3/2002	De La Torre et al.
7,214,230 B2	5/2007	Brock et al.	2002/0065507 A1	5/2002	Zadno-Azizi
7,217,240 B2	5/2007	Snow	2002/0091374 A1	7/2002	Cooper
7,239,940 B2	7/2007	Wang et al.	2002/0103417 A1	8/2002	Gazdzinski
7,250,028 B2	7/2007	Julian et al.	2002/0111535 A1	8/2002	Kim et al.
7,259,652 B2	8/2007	Wang et al.	2002/0120254 A1	8/2002	Julian et al.
7,273,488 B2	9/2007	Nakamura et al.	2002/0128552 A1	9/2002	Nowlin et al.
7,311,107 B2	12/2007	Harel et al.	2002/0140392 A1	10/2002	Borenstein et al.
7,339,341 B2	3/2008	Oleynikov et al.	2002/0147487 A1	10/2002	Sundquist et al.
7,372,229 B2	5/2008	Farritor et al.	2002/0151906 A1	10/2002	Demarais et al.
7,447,537 B1	11/2008	Funda et al.	2002/0156347 A1	10/2002	Kim et al.
7,492,116 B2	2/2009	Oleynikov et al.	2002/0171385 A1	11/2002	Kim et al.
7,566,300 B2	7/2009	Devierre et al.	2002/0173700 A1	11/2002	Kim et al.
7,574,250 B2	8/2009	Niemeyer	2002/0190682 A1	12/2002	Schempf et al.
7,637,905 B2	12/2009	Saadat et al.	2003/0020810 A1	1/2003	Takizawa et al.
7,645,230 B2	1/2010	Mikkaichi et al.	2003/0045888 A1	3/2003	Brock et al.
7,655,004 B2	2/2010	Long	2003/0065250 A1	4/2003	Chiel et al.
7,670,329 B2	3/2010	Flaherty et al.	2003/0089267 A1	5/2003	Ghorbel et al.
7,731,727 B2	6/2010	Sauer	2003/0092964 A1	5/2003	Kim et al.
7,762,825 B2	7/2010	Burbank et al.	2003/0097129 A1	5/2003	Davison et al.
7,772,796 B2	8/2010	Farritor et al.	2003/0100817 A1	5/2003	Wang et al.
7,785,251 B2	8/2010	Wilk	2003/0114731 A1	6/2003	Cadeddu et al.
7,785,333 B2	8/2010	Miyamoto et al.	2003/0135203 A1	7/2003	Wang et al.
7,789,825 B2	9/2010	Nobis et al.	2003/0139742 A1	7/2003	Wampler et al.
7,794,494 B2	9/2010	Sahatjian et al.	2003/0144656 A1	7/2003	Ocel et al.
7,865,266 B2	1/2011	Moll et al.	2003/0159535 A1	8/2003	Grover et al.
7,960,935 B2	6/2011	Farritor et al.	2003/0167000 A1	9/2003	Mullick et al.
8,021,358 B2	9/2011	Doyle et al.	2003/0172871 A1	9/2003	Scherer
8,179,073 B2	5/2012	Farritor et al.	2003/0179308 A1	9/2003	Zamorano et al.
8,231,610 B2	7/2012	Jo et al.	2003/0181788 A1	9/2003	Yokoi et al.
8,343,171 B2	1/2013	Farritor et al.	2003/0229268 A1	12/2003	Uchiyama et al.
8,353,897 B2	1/2013	Doyle et al.	2003/0229338 A1	12/2003	Irion et al.
8,679,096 B2	3/2014	Farritor et al.	2003/0230372 A1	12/2003	Schmidt
8,828,024 B2	9/2014	Farritor et al.	2004/0024311 A1	2/2004	Quaid, III
8,834,488 B2	9/2014	Farritor et al.	2004/0034282 A1	2/2004	Quaid
8,894,633 B2	11/2014	Farritor et al.	2004/0034283 A1	2/2004	Quaid
8,968,267 B2	3/2015	Nelson et al.	2004/0034302 A1	2/2004	Abovitz et al.
8,968,332 B2	3/2015	Farritor et al.	2004/0050394 A1	3/2004	Jin
8,974,440 B2	3/2015	Farritor et al.	2004/0070822 A1	4/2004	Takayama et al.
9,010,214 B2	4/2015	Markvicka et al.	2004/0099175 A1	5/2004	Perrot et al.
9,060,781 B2	6/2015	Farritor et al.	2004/0102772 A1	5/2004	Baxter et al.
9,089,353 B2	7/2015	Farritor et al.	2004/0106916 A1	6/2004	Quaid et al.
9,179,981 B2	11/2015	Farritor et al.	2004/0111113 A1	6/2004	Nakamura et al.
9,427,282 B2	8/2016	Belson et al.	2004/0117032 A1	6/2004	Roth
9,498,292 B2	11/2016	Mondry et al.	2004/0138525 A1	7/2004	Saadat et al.
9,579,088 B2	2/2017	Farritor et al.	2004/0138552 A1	7/2004	Harel et al.
9,649,020 B2	5/2017	Finlay	2004/0140786 A1	7/2004	Borenstein
9,743,987 B2	8/2017	Farritor et al.	2004/0153057 A1	8/2004	Davison
9,757,187 B2	9/2017	Farritor et al.	2004/0173116 A1	9/2004	Ghorbel et al.
9,770,305 B2	9/2017	Farritor et al.	2004/0176664 A1	9/2004	Iddan
9,883,911 B2	2/2018	Farritor et al.	2004/0215331 A1	10/2004	Chew et al.
9,888,966 B2	2/2018	Farritor et al.	2004/0225229 A1	11/2004	Viola
9,956,073 B2	5/2018	Haddock et al.	2004/0254680 A1	12/2004	Sunaoshi
10,111,711 B2	10/2018	Farritor et al.	2004/0267254 A1*	12/2004	Manzo
10,219,870 B2	3/2019	Mondry et al.	2004/0267326 A1	12/2004	Ocel et al.
10,307,199 B2	6/2019	Farritor et al.	2005/0014994 A1	1/2005	Fowler et al.
10,335,024 B2	7/2019	Rentschler et al.	2005/0021069 A1	1/2005	Feuer et al.
10,376,322 B2	8/2019	Frederick et al.	2005/0029978 A1	2/2005	Oleynikov et al.
10,470,828 B2	11/2019	Markvicka et al.	2005/0043583 A1	2/2005	Killmann et al.
10,582,973 B2	3/2020	Wilson et al.	2005/0049462 A1	3/2005	Kanazawa
10,667,883 B2	6/2020	Farritor et al.	2005/0054901 A1	3/2005	Yoshino
10,675,110 B2	6/2020	Farritor et al.	2005/0054902 A1	3/2005	Konno
			2005/0064378 A1	3/2005	Toly
			2005/0065400 A1	3/2005	Banik et al.
			2005/0083460 A1	4/2005	Hattori et al.

A61B 18/14
606/49

(56)

References Cited

U.S. PATENT DOCUMENTS

2005/0095650	A1	5/2005	Julius et al.	2009/0281377	A1	11/2009	Acosta et al.
2005/0096502	A1	5/2005	Khalili	2009/0287043	A1	11/2009	Naito et al.
2005/0143644	A1	6/2005	Gilad et al.	2009/0305210	A1	12/2009	Guru et al.
2005/0154376	A1	7/2005	Riviere et al.	2010/0010294	A1	1/2010	Conlon et al.
2005/0165449	A1	7/2005	Cadeddu et al.	2010/0016659	A1	1/2010	Weitzner
2005/0234435	A1	10/2005	Layer	2010/0016853	A1	1/2010	Burbank
2005/0239311	A1	10/2005	Yokoigawa et al.	2010/0042097	A1	2/2010	Newton et al.
2005/0283137	A1	12/2005	Doyle et al.	2010/0056863	A1	3/2010	Dejima et al.
2005/0288555	A1	12/2005	Binmoeller	2010/0069710	A1	3/2010	Yamatani et al.
2005/0288665	A1	12/2005	Woloszko	2010/0069940	A1	3/2010	Miller et al.
2006/0020272	A1	1/2006	Gildenberg	2010/0081875	A1	4/2010	Fowler et al.
2006/0046226	A1	3/2006	Bergler et al.	2010/0139436	A1	6/2010	Kawashima et al.
2006/0100501	A1	5/2006	Berkelman et al.	2010/0185212	A1	7/2010	Sholev
2006/0119304	A1	6/2006	Farritor et al.	2010/0198231	A1	8/2010	Scott
2006/0149135	A1	7/2006	Paz	2010/0204713	A1	8/2010	Ruiz Morales
2006/0152591	A1	7/2006	Lin	2010/0245549	A1	9/2010	Allen et al.
2006/0155263	A1	7/2006	Lipow	2010/0250000	A1	9/2010	Blumenkranz et al.
2006/0195015	A1	8/2006	Mullick et al.	2010/0262162	A1	10/2010	Omori
2006/0196301	A1	9/2006	Oleynikov et al.	2010/0286480	A1	11/2010	Peine et al.
2006/0198619	A1	9/2006	Oleynikov et al.	2010/0292691	A1	11/2010	Broгна
2006/0241570	A1	10/2006	Wilk	2010/0312102	A1	12/2010	Barnes et al.
2006/0241732	A1	10/2006	Denker et al.	2010/0318059	A1	12/2010	Farritor et al.
2006/0253109	A1	11/2006	Chu	2011/0015569	A1	1/2011	Kirschenman et al.
2006/0258954	A1	11/2006	Timberlake et al.	2011/0020779	A1	1/2011	Hannaford et al.
2007/0032701	A1	2/2007	Fowler et al.	2011/0054462	A1	3/2011	Ellman
2007/0043397	A1	2/2007	Ocel et al.	2011/0071347	A1	3/2011	Rogers et al.
2007/0055342	A1	3/2007	Wu et al.	2011/0071544	A1	3/2011	Steger et al.
2007/0080658	A1	4/2007	Farritor et al.	2011/0077478	A1	3/2011	Freeman et al.
2007/0106113	A1	5/2007	Ravo	2011/0098529	A1	4/2011	Ostrovsky et al.
2007/0123748	A1	5/2007	Meglan	2011/0132960	A1	6/2011	Whitman et al.
2007/0135803	A1	6/2007	Belson	2011/0152615	A1	6/2011	Schostek et al.
2007/0142725	A1	6/2007	Hardin et al.	2011/0224605	A1	9/2011	Farritor et al.
2007/0156019	A1	7/2007	Larkin et al.	2011/0230894	A1	9/2011	Simaan et al.
2007/0156211	A1	7/2007	Wood et al.	2011/0237890	A1	9/2011	Farritor et al.
2007/0167955	A1	7/2007	Arnault De La Menardiere et al.	2011/0238080	A1	9/2011	Ranjit et al.
2007/0225633	A1	9/2007	Wood et al.	2011/0245888	A1	10/2011	Badelt et al.
2007/0225634	A1	9/2007	Wood et al.	2011/0264078	A1	10/2011	Lipow et al.
2007/0241714	A1	10/2007	Okeynikov et al.	2011/0270443	A1	11/2011	Kamiya et al.
2007/0244520	A1	10/2007	Ferren et al.	2011/0276046	A1	11/2011	Heimbecher et al.
2007/0250064	A1	10/2007	Darois et al.	2012/0029727	A1	2/2012	Malik
2007/0255273	A1	11/2007	Fernandez et al.	2012/0035582	A1	2/2012	Nelson et al.
2008/0004634	A1	1/2008	Farritor et al.	2012/0109150	A1	5/2012	Blackwell et al.
2008/0015565	A1	1/2008	Davison	2012/0116362	A1	5/2012	Kieturakis
2008/0015566	A1	1/2008	Livneh	2012/0179168	A1	7/2012	Farritor et al.
2008/0033569	A1	2/2008	Ferren et al.	2012/0253515	A1	10/2012	Coste-Maniere et al.
2008/0045803	A1	2/2008	Williams et al.	2013/0041360	A1	2/2013	Farritor et al.
2008/0058835	A1	3/2008	Farritor et al.	2013/0131695	A1	5/2013	Scarfogliero et al.
2008/0058989	A1	3/2008	Oleynikov et al.	2013/0345717	A1	12/2013	Markvicka et al.
2008/0103440	A1	5/2008	Ferren et al.	2014/0001234	A1*	1/2014	Shelton, IV A61B 17/068 74/25
2008/0109014	A1	5/2008	De La Pena	2014/0039515	A1	2/2014	Mondry et al.
2008/0111513	A1	5/2008	Farritor et al.	2014/0046340	A1	2/2014	Wilson et al.
2008/0119870	A1	5/2008	Williams	2014/0058205	A1	2/2014	Frederick et al.
2008/0132890	A1	6/2008	Woloszko et al.	2014/0249474	A1	9/2014	Suon et al.
2008/0161804	A1	7/2008	Rioux et al.	2014/0303434	A1	10/2014	Farritor et al.
2008/0164079	A1	7/2008	Jacobsen	2014/0373652	A1	12/2014	Zergiebel et al.
2008/0183033	A1	7/2008	Bern et al.	2015/0051446	A1	2/2015	Farritor et al.
2008/0221591	A1	9/2008	Farritor et al.	2015/0190170	A1	7/2015	Frederick et al.
2008/0269557	A1	10/2008	Marescaux et al.	2016/0143688	A1	5/2016	Orban, III et al.
2008/0269562	A1	10/2008	Marescaux et al.	2016/0291915	A1	10/2016	Panchapakesan et al.
2009/0012532	A1	1/2009	Blackwell et al.	2017/0258536	A1	9/2017	Yeung et al.
2009/0020724	A1	1/2009	Paffrath	2018/0056527	A1	3/2018	Farritor et al.
2009/0024142	A1	1/2009	Ruiz Morales	2018/0140377	A1	5/2018	Reichenbach et al.
2009/0048612	A1	2/2009	Farritor et al.	2019/0090965	A1	3/2019	Farritor et al.
2009/0054909	A1	2/2009	Farritor et al.	2020/0214775	A1	7/2020	Farritor et al.
2009/0069821	A1	3/2009	Farritor et al.	2020/0352667	A1	11/2020	Kapadia et al.
2009/0076536	A1	3/2009	Rentschler et al.	2021/0045836	A1	2/2021	Farritor et al.
2009/0137952	A1	5/2009	Ramamurthy et al.	2021/0068913	A1	3/2021	Wang et al.
2009/0143787	A9	6/2009	De La Pena	2021/0169592	A1	6/2021	Robinson et al.
2009/0163929	A1	6/2009	Yeung et al.	2021/0290314	A1	9/2021	Sachs et al.
2009/0171373	A1	7/2009	Farritor et al.	2021/0290323	A1	9/2021	Sachs et al.
2009/0234369	A1	9/2009	Bax et al.	2022/0000569	A1	1/2022	Farritor et al.
2009/0236400	A1	9/2009	Cole et al.				
2009/0240246	A1	9/2009	Deville et al.				
2009/0247821	A1	10/2009	Rogers				
2009/0248038	A1	10/2009	Blumenkranz et al.				

FOREIGN PATENT DOCUMENTS

CN	104224258	A	12/2014
DE	102010040405	A1	3/2012
EP	105656	A2	4/1984
EP	279591	A1	8/1988

(56)

References Cited

FOREIGN PATENT DOCUMENTS

EP	1354670	A1	10/2003
EP	2286756	A1	2/2011
EP	2329787	A2	6/2011
EP	2563261	A1	3/2013
EP	2647339	A1	10/2013
EP	2684528	A1	1/2014
EP	2123225	B1	12/2014
EP	2815705	A1	12/2014
EP	2881046	A2	6/2015
EP	2937047	A1	10/2015
JP	H04144533	A	5/1992
JP	H05115425	A	5/1993
JP	H05184535	A	7/1993
JP	H06507809	A	9/1994
JP	H06508049	A	9/1994
JP	H07016235	A	1/1995
JP	H07136173	A	5/1995
JP	H07306155	A	11/1995
JP	H08224248	A	9/1996
JP	2001500510	A	1/2001
JP	2001505810	A	5/2001
JP	2002000524	A	1/2002
JP	2003220065	A	8/2003
JP	2004180781	A	7/2004
JP	2004180858	A	7/2004
JP	2004322310	A	11/2004
JP	2004329292	A	11/2004
JP	2009106606	A	5/2009
JP	2010533045	A	10/2010
JP	2010536436	A	12/2010
JP	2011504794	A	2/2011
JP	2011045500	A	3/2011
JP	2011115591	A	6/2011
JP	2017527392	A	9/2017
KR	20100029087	A	3/2010
WO	9221291	A2	12/1992
WO	9610957	A1	4/1996
WO	9639944	A1	12/1996
WO	0189405	A1	11/2001
WO	02082979	A2	10/2002
WO	02100256	A2	12/2002
WO	2005009211	A2	2/2005
WO	2005044095	A1	5/2005
WO	2006005075	A2	1/2006
WO	2006052927	A2	5/2006
WO	2006079108	A1	7/2006
WO	2007011654	A1	1/2007
WO	2007111571	A1	10/2007
WO	2007146987	A2	12/2007
WO	2007149559	A2	12/2007
WO	2009014917	A2	1/2009
WO	2009023851	A1	2/2009
WO	2009144729	A1	12/2009
WO	2010042611	A1	4/2010
WO	2010046823	A1	4/2010
WO	2010050771	A2	5/2010
WO	2011060311	A2	5/2011
WO	2011075693	A1	6/2011
WO	2011088387	A2	7/2011
WO	2011118646	A1	9/2011
WO	2011135503	A1	11/2011
WO	2013009887	A1	1/2013
WO	2014011238	A2	1/2014
WO	2015088655	A1	6/2015
WO	2019099903	A1	5/2019

OTHER PUBLICATIONS

Fearing et al., "Wing Transmission for a Micromechanical Flying Insect," Proceedings of the 2000 IEEE International Conference on Robotics & Automation, Apr. 2000; 1509-1516.

Fireman et al., "Diagnosing small bowel Crohn's disease with wireless capsule endoscopy," Gut 2003; 52: 390-392.

Flynn et al., "Tomorrow's Surgery: micromotors and microbots for minimally invasive procedures," Minimally Invasive Surgery & Allied Technologies.

Franklin et al., "Prospective Comparison of Open vs. Laparoscopic Colon Surgery for Carcinoma: Five-Year Results," Dis Colon Rectum, 1996; 39: S35-S46.

Franzino, "The Laprotek Surgical System and the Next Generation of Robotics," Surg Clin North Am, 2003 83(6), pp. 1317-1320.

Fraulob et al., "Miniature assistance module for robot-assisted heart surgery," Biomed. Tech. 2002, 47 Suppl. 1, Pt. 1: 12-15.

Fukuda et al., "Mechanism and Swimming Experiment of Micro Mobile Robot in Water," Proceedings of the 1994 IEEE International Conference on Robotics and Automation, 1994: 814-819.

Fukuda et al., "Micro Active Catheter System with Multi Degrees of Freedom," Proceedings of the IEEE International Conference on Robotics and Automation, May 1994, pp. 2290-2295.

Fuller et al., "Laparoscopic Trocar Injuries: A Report from a U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) Systematic Technology Assessment of Medical Products (STAMP) Committee," U.S. Food and Drug Administration, available at <http://www.fda.gov/oc/Finalized>: Nov. 7, 2003; Updated: Jun. 24, 2005, 11 pp.

Glukhovskiy et al., "The development and application of wireless capsule endoscopy," Int. J. Med. Robot. Comput. Assisi. Surgery, 2004; 1(1): 114-123.

Way et al., (editors), "Fundamentals of Laparoscopic Surgery," Churchill Livingstone Inc., 1995, 14 pp.

Wolfe et al., "Endoscopic Cholecystectomy: An analysis of Complications," Arch. Surg. Oct. 1991; 126: 1192-1196.

Worn et al., "Espirito Project No. 33915: Miniaturised Robot for Micro Manipulation (MINIMAN)", Nov. 1998; <http://www.ipr.ira-ujka.de/~microbol/miniman>.

Yu et al., "Microrobotic Cell Injection," Proceedings of the 2001 IEEE International Conference on Robotics and Automation, May 2001; 620-625.

Yu, BSN, RN, "M2ATM Capsule Endoscopy a Breakthrough Diagnostic Tool for Small Intestine Imaging," vol. 25, No. 1, Gastroenterology Nursing, pp. 24-27.

Mack, "Minimally Invasive and Robotic Surgery," JAMA, Feb. 2001; 285(5): 568-572.

Mei et al., "Wireless Drive and Control of a Swimming Microrobot," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, May 2002: 1131-1136.

Melvin et al., "Computer-Enhanced vs. Standard Laparoscopic Antireflux Surgery," J Gastrointest Surg 2002; 6: 11-16.

Menciassi et al., "Locomotion of a Leffed Capsule in the Gastrointestinal Tract: Theoretical Study and Preliminary Technological Results," IEEE Int. Conf. on Engineering in Medicine and Biology, San Francisco, CA, pp. 2767-2770, Sep. 2004.

Menciassi et al., "Robotic Solutions and Mechanisms for a Semi-Autonomous Endoscope," Proceedings of the 2002 IEEE/RSJ Intl. Conference on Intelligent Robots and Systems, Oct. 2002; 1379-1384.

Menciassi et al., "Shape memory alloy clamping devices of a capsule for monitoring tasks in the gastrointestinal tract," J. Micromech. Microeng, 2005, 15: 2045-2055.

Meron, "The development of the swallowable video capsule (M2A)," Gastrointestinal Endoscopy 2000; 52 6: 817-819.

Micron, <http://www.micron.com>, 2006, 1/4-inch VGA NTSC/PAL CMOS Digital Image Sensor, 98 pp.

Midday Jeff et al., "Material Handling System for Robotic natural Orifice Surgery", Proceedings of the 2011 Design of medical Devices Conference, Apr. 12-14, 2011, Minneapolis, MN, 4 pages.

Miller, Ph.D., et al., "In-Vivo Stereoscopic Imaging System with 5 Degrees-of-Freedom for Minimal Access Surgery," Dept. of Computer Science and Dept. of Surgery, Columbia University, New York, NY, 7 pp.

Munro (2002), "Laparoscopic access: complications, technologies, and techniques," Curr Opin. Obstet. Gynecol., 14(4): 365-74.

Nio et al., "Efficiency of manual vs robotic (Zeus) assisted laparoscopic surgery in the performance of standardized tasks," Surg Endosc, 2002; 16: 412-415.

(56)

References Cited**OTHER PUBLICATIONS**

- Oleynikov et al., "In Vivo Camera Robots Provide Improved Vision for Laparoscopic Surgery," *Computer Assisted Radiology and Surgery (CARS)*, Chicago, IL, Jun. 23-26, 2004.
- Oleynikov et al., "In Vivo Robotic Laparoscopy," *Surgical Innovation*, Jun. 2005, 12(2): 177-181.
- Oleynikov et al., "Miniature Robots Can Assist in Laparoscopic Cholecystectomy," *Journal of Surgical Endoscopy*, 19-4: 473-476, 2005.
- O'Neill, "Surgeon takes new route to gallbladder," *The Oregonian*, Jun. 2007, 2 pp.
- Orlando et al., (2003), "Needle and Trocar Injuries in Diagnostic Laparoscopy under Local Anesthesia: What Is the True Incidence of These Complications?" *Journal of Laparoendoscopic & Advanced Surgical Techniques* 13(3): 181-184.
- Palm, William, "Rapid Prototyping Primer" May 1998 (revised Jul. 30, 2002) (<http://www.me.psu.edu/lamancusa/rapidpro/primer/chapter2.htm>).
- Park et al., "Trocar-less Instrumentation for Laparoscopy: Magnetic Positioning of Intra-abdominal Camera and Retractor," *Ann Surg.* Mar. 2007; 245(3): 379-384.
- Park et al., "Experimental studies of transgastric gallbladder surgery: cholecystectomy and cholecystogastric anastomosis (video)," *Gastrointestinal Endoscopy*, 2005; 61(4): 601-606.
- Patronik et al., "Development of a Tethered Epicardial Crawler for Minimally Invasive Cardiac Therapies," *IEEE*, pp. 239-240.
- Patronik et al., "Crawling on the Heart: A Mobile Robotic Device for Minimally Invasive Cardiac Interventions," *MICCAI*, 2004, pp. 9-16.
- Patronik et al., "Preliminary evaluation of a mobile robotic device for navigation and intervention on the beating heart," *Computer Aided Surgery*, 10(4): 225-232, Jul. 2005.
- Peirs et al., "A miniature manipulator for integration in a self-propelling endoscope," *Sensors and Actuators A*, 2001, 92: 343-349.
- Peters, "Minimally Invasive Colectomy: Are the Potential Benefits Realized?" *Dis Colon Rectum* 1993; 36: 751-756.
- Phoe et al., "Analysis and Development of Locomotion Devices for the Gastrointestinal Tract," *IEEE Transaction on Biomedical Engineering*, vol. 49, No. 6, Jun. 2002, pp. 613-616.
- Phoe et al., "Development of Microrobotic Devices for Locomotion in the Human Gastrointestinal Tract," *International Conference on Computational Intelligence, Robotics and Autonomous Systems (CIRAS 2001)*, Nov. 28-30, 2001, Singapore.
- Platt et al., "In Vivo Robotic Cameras can Enhance Imaging Capability During Laparoscopic Surgery," in the *Proceedings of the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) Scientific Conference*, Ft. Lauderdale, FL, Apr. 13-16, 2005, 1 pg.
- Rentschler et al., "Mobile In Vivo Biopsy and Camera Robot," *Studies in Health and Infonnatics Medicine Meets Virtual Reality*, vol. 119., pp. 449-454, IOS Press, Long Beach, CA, 2006.
- Rentschler et al., "Mobile In Vivo Biopsy Robot," *IEEE International Conference on Robotics and Automation*, Orlando, Florida, May 2006, pp. 4155-4160.
- Rentschler et al., "Miniature in vivo Robots for Remote and Harsh Environments," *IEEE Transactions on Information Technology in Biomedicine*. Jan. 2006; 12(1): 66-75.
- Rentschler et al., "An In Vivo Mobile Robot for Surgical Vision and Task Assistance," *Journal of Medical Devices*, Mar. 2007, vol. 1: 23-29.
- Rentschler et al., "In vivo Mobile Surgical Robotic Task Assistance," 1 pg.
- European Patent Office, "Extended European Search Report", From Application No. 24206509, Dated Feb. 19, 2025, pp. 14.
- Kang et al., "Robotic Assistants Aid Surgeons During Minimally Invasive Procedures," *IEEE Engineering in Medicine and Biology*, Jan.-Feb. 2001; pp. 94-104.
- Kantsevov et al., "Endoscopic gastrojejunostomy with survival in a porcine model," *Gastrointestinal Endoscopy*, 2005; 62(2): 287-292.
- Kantsevov et al., "Transgastric endoscopic splenectomy," *Surgical Endoscopy*, 2006; 20: 522-525.
- Kazemier et al. (1998), "Vascular Injuries During Laparoscopy," *J. Am. Coli. Surg.* 186(5): 604-5.
- Keller et al., Design of the pediatric arm rehabilitation robot ChARMin, 2014, IEEE, p. 530-535 (Year: 2014).
- Kim, "Early Experience with Telemnulative Robot-Assisted Laparoscopic Cholecystectomy Using da Vinci," *Surgical Laparoscopy, Endoscopy & Percutaneous Techniques*, 2002; 12(1):33-40.
- Ko et al., "Per-Oral transgastric abdominal surgery," *Chinese Journal of Digestive Diseases*, 2006; 7: 67-70.
- Lafuillarde et al., "Laparoscopic Nissen Fundoplication: Five-year Results and Beyond," *Arch/Surg*, Feb. 2001; 136:180-184.
- Leggett et al. (2002), "Aortic injury during laparoscopic fundoplication," *Surg. Endoscopy* 16(2): 362.
- Li et al. (2000), "Microvascular Anastomoses Performed in Rats Using a Microsurgical Telemnulator," *Comp. Aid. Surg.* 5: 326-332.
- Liem et al., "Comparison of Conventional Anterior Surgery and Laparoscopic Surgery for Inguinal-hernia Repair," *New England Journal of Medicine*, 1997; 336 (22): 1541-1547.
- Macfarlane et al., "Force-Feedback Grasper Helps Restore the Sense of Touch in Minimally Invasive Surgery," *Journal of Gastrointestinal Surgery*, 1999; 3: 278-285.
- Mack et al., "Present Role of Thoracoscopy in the Diagnosis and Treatment of Diseases of the Chest," *Ann Thorac Surgery*, 1992; 54: 403-409.
- Rentschler et al., "In vivo Robotics during the NEEMO 9 Mission," *Medicine Meets Virtual Reality*, Feb. 2007, 1 pg.
- Rentschler et al., "In Vivo Robots for Laparoscopic Surgery," *Studies in Health Technology and Infonnatics—Medicine Meets Virtual Reality*, ISO Press, Newport Beach, CA, 2004a, 98: 316-322.
- Rentschler et al., "Mechanical Design of Robotic In Vivo Wheeled Mobility," *ASME Journal of Mechanical Design*, 2006, pp. 1-11.
- Rentschler et al., "Mobile In Vivo Camera Robots Provide Sole Visual Feedback for Abdominal Exploration and Cholecystectomy," *Journal of Surgical Endoscopy*, 20-1: 135-138, 2006b.
- Rentschler et al., "Mobile In Vivo Robots Can Assist in Abdominal Exploration," from the *Proceedings of the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) Scientific Conference*, Ft. Lauderdale, FL, Apr. 13-16, 2005b.
- Rentschler et al., "Modeling, Analysis, and Experimental Study of In Vivo Wheeled Robotic Mobility," *IEEE Transactions on Robotics*, 22 (2): 308-321, 2005c.
- Rentschler et al., "Natural Orifice Surgery with an Endoluminal Mobile Robot," *The Society of American Gastrointestinal Endoscopic Surgeons*, Dallas, TX, Apr. 2006d, 14 pp.
- Rentschler et al., "Theoretical and Experimental Analysis of In Vivo Wheeled Mobility," *ASME Design Engineering Technical Conferences: 28th Biennial Mechanisms and Robotics Conference*, Salt Lake City, Utah, Sep. 28-Oct. 2, 2004, pp. 1-9.
- Rentschler et al., "Toward In Vivo Mobility," *Studies in Health Technology and Infonnatics—Medicine Meets Virtual Reality*, ISO Press, Long Beach, CA, 2005a, III: 397-403.
- Riviere et al., "Toward Active Tremor Canceling in Handheld Microsurgical Instruments," *IEEE Transactions on Robotics and Automation*, Oct. 2003, 19(5): 793-800.
- Rosen et al., "Force Controlled and Teleoperated Endoscopic, Grasper for Minimally Invasive Surgery-Experimental Performance Evaluation," *IEEE Transactions of Biomedical Engineering*, Oct. 1999; 46(10): 1212-1221.
- Rosen et al., "Objective Laparoscopic Skills Assessments of Surgical Residents Using Hidden Markov Models Based on Haptic Information and Tool/Tissue Interactions," *Studies in Health Technology and Infonnatics-Medicine Meets Virtual Reality*, Jan. 2001, 7 pp.
- Rosen et al., "Spherical Mechanism Analysis of a Surgical Robot for Minimally Invasive Surgery—Analytical and Experimental Approaches," *Studies in Health Technology and Infonnatics-Medicine Meets Virtual Reality*, pp. 442-448, Jan. 2005.

(56)

References Cited**OTHER PUBLICATIONS**

- Rosen et al., "Task Decomposition of Laparoscopic Surgery for Objective Evaluation of Surgical Residents' Learning Curve Using Hidden Markov Model," *Computer Aided Surgery*, vol. 7, pp. 49-61, 2002.
- Rosen et al., "The Blue Dragon—A System of Measuring the Kinematics and the Dynamics of Minimally Invasive Surgical Tools In-Vivo," *Proc. of the 2002 IEEE International Conference on Robotics and Automation*, Washington, DC, pp. 1876-1881, May 2002.
- Ruurda et al., "Robot-Assisted surgical systems: a new era in laparoscopic surgery," *Ann R. Coll Surg Engl.*, 2002; 84: 223-226.
- Ruurda et al., "Feasibility of Robot-Assisted Laparoscopic Surgery," *Surgical Laparoscopy, Endoscopy & Percutaneous Techniques*, 2002; 12(1):41-45.
- Sackier et al., "Robotically assisted laparoscopic surgery," *Surgical Endoscopy*, 1994; 8: 63-66.
- Salky, "What is the Penetration of Endoscopic Techniques into Surgical Practice?" *Digestive Surgery*, 2000; 17:422-426.
- Satava, "Surgical Robotics: The Early Chronicles," *Surgical Laparoscopy, Endoscopy & Percutaneous Techniques*, 2002; 12(1): 6-16.
- Schippers et al., (1996) "Requirements and Possibilities of Computer-Assisted Endoscopic Surgery," In: *Computer Integrated Surgery: Technology and Clinical Applications*, pp. 561-565.
- Schurr et al., "Robotics and Telemanipulation Technologies for Endoscopic Surgery," *Surgical Endoscopy*, 2000; 14: 375-381.
- Schwartz, "In the Lab: Robots that Slink and Squirm," *The New York Times*, Mar. 27, 2007, 4 pp.
- Sharp LL-151-3D, <http://www.sharp3d.com>, 2006, 2 pp.
- Slatkin et al., "The Development of a Robotic Endoscope," *Proceedings of the 1995 IEEE International Conference on Robotics and Automation*, pp. 162-171, 1995.
- Smart Pill "Fastastic Voyage: Smart Pill to Expand Testing," <http://www.smartpilldiagnostics.com>, Apr. 13, 2005, 1 pg.
- Sodeyama et al., "A shoulder structure of muscle-driven humanoid with shoulder blades, 2005, IEEE, p. 1-6 (Year: 2005).
- Southern Surgeons Club (1991), "A prospective analysis of 1518 laparoscopic cholecystectomies," *N. Eng. J. Med.* 324 (16): 1073-1078.
- Stefanini et al., "Modeling and Experiments on a Legged Microrobot Locomoting in a Tubular Compliant and Slippery Environment," *Int. Journal of Robotics Research*, vol. 25, No. 5-6, pp. 551-560, May-Jun. 2006.
- Stiff et al., "Long-term Pain: Less Common After Laparoscopic than Open Cholecystectomy," *British Journal of Surgery*, 1994; 81: 1368-1370.
- Stoianovici et al., "Robotic Tools for Minimally Invasive Urologic Surgery," *Jan. 1, 2002*, pp. 1-17.
- Strong et al., "Efficacy of Novel Robotic Camera vs. a Standard Laproscopic Camera," *Surgical Innovation* vol. 12, No. 4, Dec. 2005, Westminster Publications, Inc., pp. 315-318.
- Suzumori et al., "Development of Flexible Microactuator and its Applications to Robotics Mechanisms," *Proceedings of the IEEE International Conference on Robotics and Automation*, 1991: 1622-1627.
- Taylor et al., "A Telerobotic Assistant for Laparoscopic Surgery," *IEEE Eng Med Biol*, 1995; 279-287.
- Tendick et al., (1993), "Sensing and Manipulation Problems in Endoscopic Surgery: Experiment, Analysis, and Observation," *Presence* 2(1): 66-81.
- Tendick et al., "Applications of Micromechatronics in Minimally Invasive Surgery," *IEEE/ASME Transactions on Mechatronics*, 1998; 3(1): 34-42.
- Thomann et al., "The Design of a new type of Micro Robot for the Intestinal Inspection," *Proceedings of the 2002 IEEE Intl. Conference on Intelligent Robots and Systems*, Oct. 2002: 1385-1390.
- U.S. Appl. No. 60/180,960, filed Feb. 2000.
- U.S. Appl. No. 60/956,032, filed Aug. 15, 2007.
- U.S. Appl. No. 60/983,445, filed Oct. 29, 2007.
- U.S. Appl. No. 60/990,062, filed Nov. 26, 2007.
- U.S. Appl. No. 60/990,076, filed Nov. 26, 2007.
- U.S. Appl. No. 60/990,086, filed Nov. 26, 2007.
- U.S. Appl. No. 60/990,106, filed Nov. 26, 2007.
- U.S. Appl. No. 60/990,470, filed Nov. 27, 2007.
- U.S. Appl. No. 61/025,346, filed Feb. 1, 2008.
- U.S. Appl. No. 61/030,588, filed Feb. 22, 2008.
- U.S. Appl. No. 61/030,617, filed Feb. 22, 2008.
- Abbott et al., "Design of an Endoluminal Notes Robotic System," from the *Proceedings of the 2007 IEEE/RSJ Int'l Conf. on Intelligent Robot Systems*, San Diego, CA, Oct. 29-Nov. 2, 2007, pp. 410-416.
- Abbou et al., "Laparoscopic Radical Prostatectomy with a Remote Controlled Robot," *The Journal of Urology*, Jun. 2001, 165: 1964-1966.
- Albers et al., Design and development process of a humanoid robot upper body through experimentation, 2004, IEEE, p. 77-92 (Year: 2004).
- Allendorf et al., "Postoperative Immune Function Varies Inversely with the Degree of Surgical Trauma in a Murine Model," *Surgical Endoscopy* 1997; 11:427-430.
- Ang, "Active Tremor Compensation in Handheld Instrument for Microsurgery," *Doctoral Dissertation*, tech report CMU-RI-TR-04-28, Robotics Institute, Carnegie Mellon University, May 2004, 167 pp.
- Atmel 80C5X2 Core, <http://www.atmel.com>, 2006, 186 pp.
- Bailey et al., "Complications of Laparoscopic Surgery," *Quality Medical Publishers, Inc.*, 1995, 25 pp.
- Ballantyne, "Robotic Surgery, Telerobotic Surgery, Telepresence, and Telementoring," *Surgical Endoscopy*, 2002; 16: 1389-1402.
- Bauer et al., "Case Report: Remote Percutaneous Renal Percutaneous Renal Access Using a New Automated Telesurgical Robotic System," *Telemedicine Journal and e-Health* 2001; (4): 341-347.
- Begos et al., "Laparoscopic Cholecystectomy: From Gimmick to Gold Standard," *J Clin Gastroenterol*, 1994; 19(4): 325-330.
- Berg et al., "Surgery with Cooperative Robots," *Medicine Meets Virtual Reality*, Feb. 2007, 1 pg.
- Breda et al., "Future developments and perspectives in laparoscopy," *Eur. Urology* 2001; 40(1): 84-91.
- Breedveld et al., "Design of Steerable Endoscopes to Improve the Visual Perception of Depth During Laparoscopic Surgery," *ASME, Jan. 2004*; vol. 126, pp. 1-5.
- Breedveld et al., "Locomotion through the Intestine by means of Rolling Stents," *Proceedings of the ASME Design Engineering Technical Conferences*, 2004, pp. 1-7.
- Calafiore et al., Multiple Arterial Conduits Without Cardiopulmonary Bypass: Early Angiographic Results, *Ann Thorac Surg*, 1999; 67: 450-456.
- Camarillo et al., "Robotic Technology in Surgery: Past, Present and Future," *The American Journal of Surgery*, 2004; 188: 28-15.
- Cavusoglu et al., "Telesurgery and Surgical Simulation: Haptic Interfaces to Real and Virtual Surgical Environments," in McLaughlin, M.L., Hespanha, J.P., and Sukhatme, G., editors. *Touch in virtual environments*, IMSC Series in Multimedia 2001, 28pp.
- Cavusoglu et al., "Robotics for Telesurgery: Second Generation Berkeley/UCSF Laparoscopic Telesurgical Workstation and Looking Towards the Future Applications," *Industrial Robot: An International Journal*, 2003; 30(1): 22-29.
- Chanthasopeephan et al., (2003), "Measuring Forces in Liver Cutting: New Equipment and Experimental Results," *Annals of Biomedical Engineering* 31: 1372-1382.
- Choi et al., "Flexure-based Manipulator for Active Handheld Microsurgical Instrument," *Proceedings of the 27th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS)*, Sep. 2005, 4 pp.
- Cleary et al., "State of the Art in Surgical Robotics: Clinical Applications and Technology Challenges," *Computer Aided Surgery*, Jan. 1, 2002, pp. 312-328, vol. 6.
- Cuschieri, "Technology for Minimal Access Surgery," *BMJ*, 1999, 319: 1-6.
- Dakin et al., "Comparison of laparoscopic skills performance between standard instruments and two surgical robotic systems," *Surg Endosc.*, 2003; 17: 574-579.

(56)

References Cited

OTHER PUBLICATIONS

Dumpert et al., "Improving in Vivo Robot Vision Quality," from the Proceedings of Medicine Meets Virtual Reality, Long Beach, CA, Jan. 26-29, 2005. 1 pg.

Dumpert et al., "Stereoscopic In Vivo Surgical Robots," IEEE Sensors Special Issue on In Vivo Sensors for Medicine, Jan. 2007, 10 pp.

Falcone et al., "Robotic Surgery," Clin. Obstet. Gynecol. 2003, 46(1): 37-43.

Gong et al., "Wireless endoscopy," Gastrointestinal Endoscopy 2000; 51(6): 725-729.

Gopura et al., Mechanical designs of active upper-limb exoskeleton robots: State-of-the-art and design difficulties, 2009, IEEE, p. 178-187 (Year: 2009).

Grady, "Doctors Try New Surgery for Gallbladder Removal," The New York Times, Apr. 20, 2007, 3 pp.

Green, "Telepresence Surgery", Jan. 1, 1995, Publisher: IEEE Engineering in Medicine and Biology.

Guber et al., "Miniaturized Instrument Systems for Minimally Invasive Diagnosis and Therapy," Biomedizinische Technik. 2002, Band 47, Ergänzungsband 1.

Hanly et al., "Value of the SAGES Learning Center in introducing new technology," Surgical Endoscopy, 2004; 19(4): 477-483.

Hanly et al., "Robotic Abdominal Surgery," The American Journal of Surgery 188 (Suppl. to Oct. 1994): 19S-26S, 2004.

Heikkinen et al., "Comparison of laparoscopic and open Nissen fundoplication two years after operation: A prospective randomized trial," Surgical Endoscopy, 2000; 14: 1019-1023.

Hissink, "Olympus Medical develops capsule camera technology," Dec. 2004, accessed Aug. 29, 2007, <http://www.letsgodigital.org>, 3 pp.

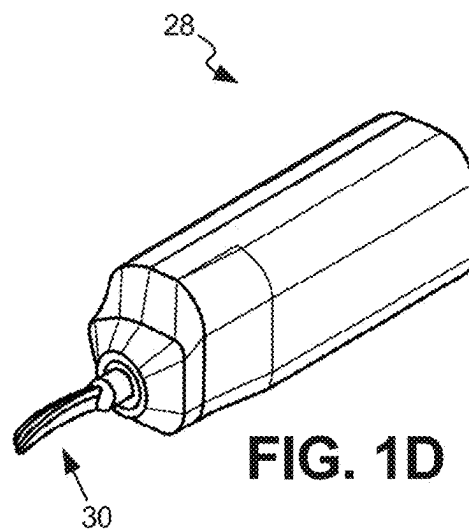
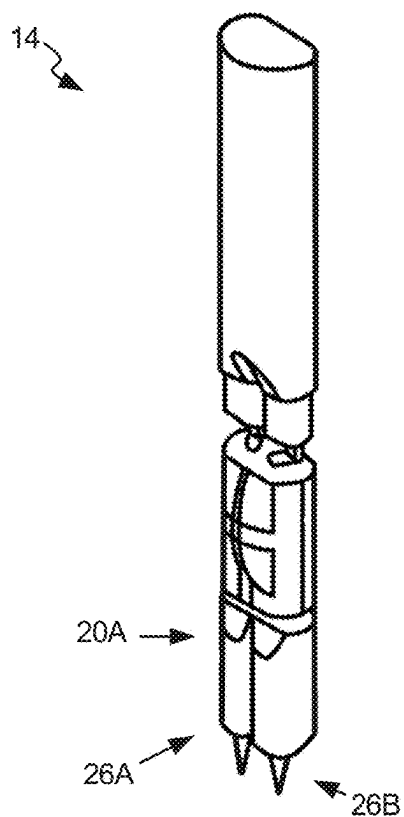
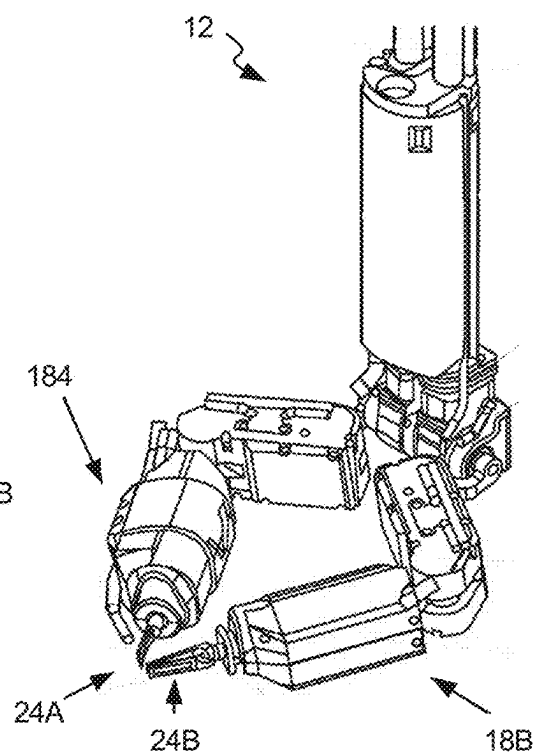
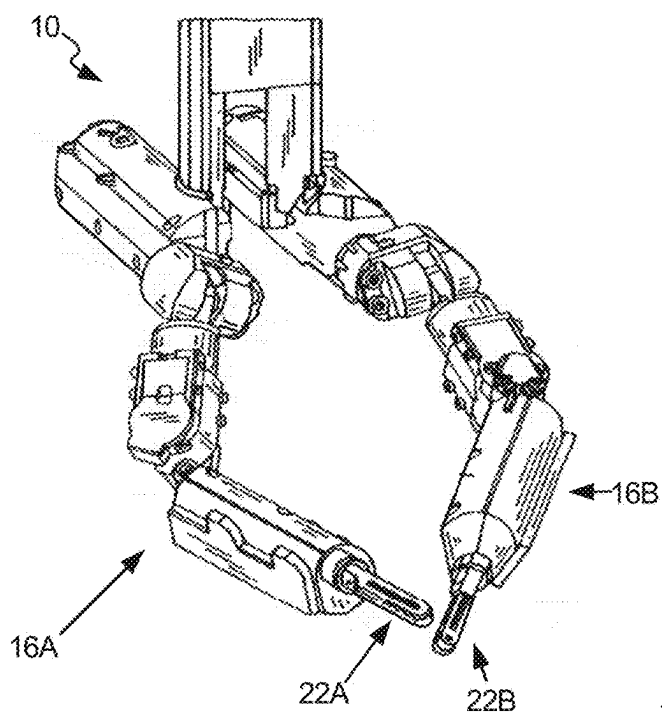
Horgan et al., "Technical Report: Robots in Laparoscopic Surgery," Journal of Laparoendoscopic & Advanced Surgical Techniques, 2001; 11(6): 415-419.

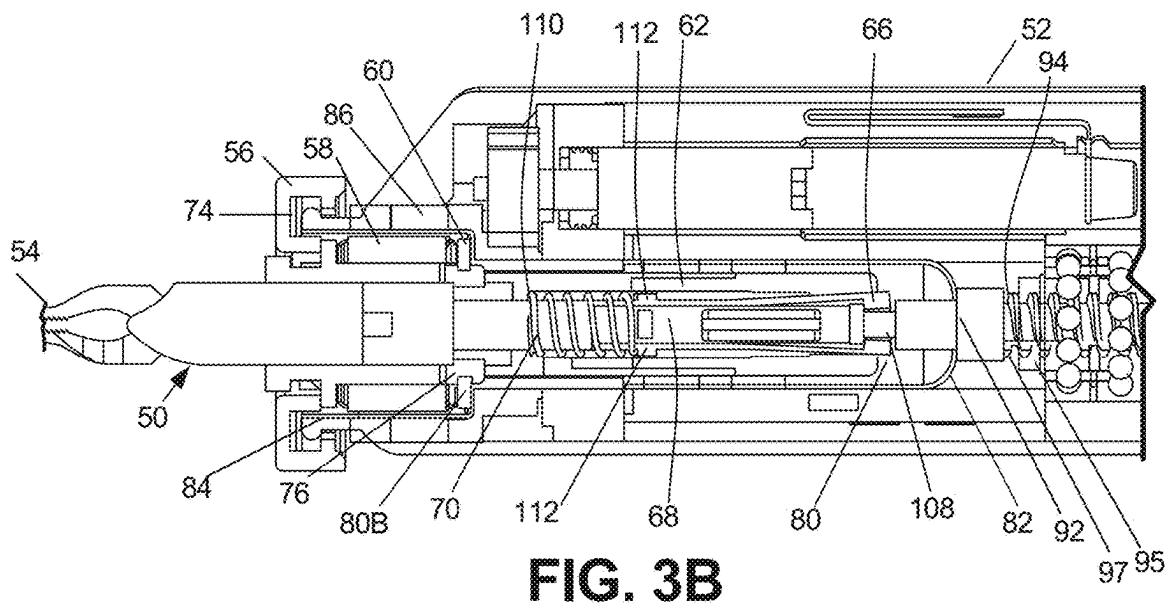
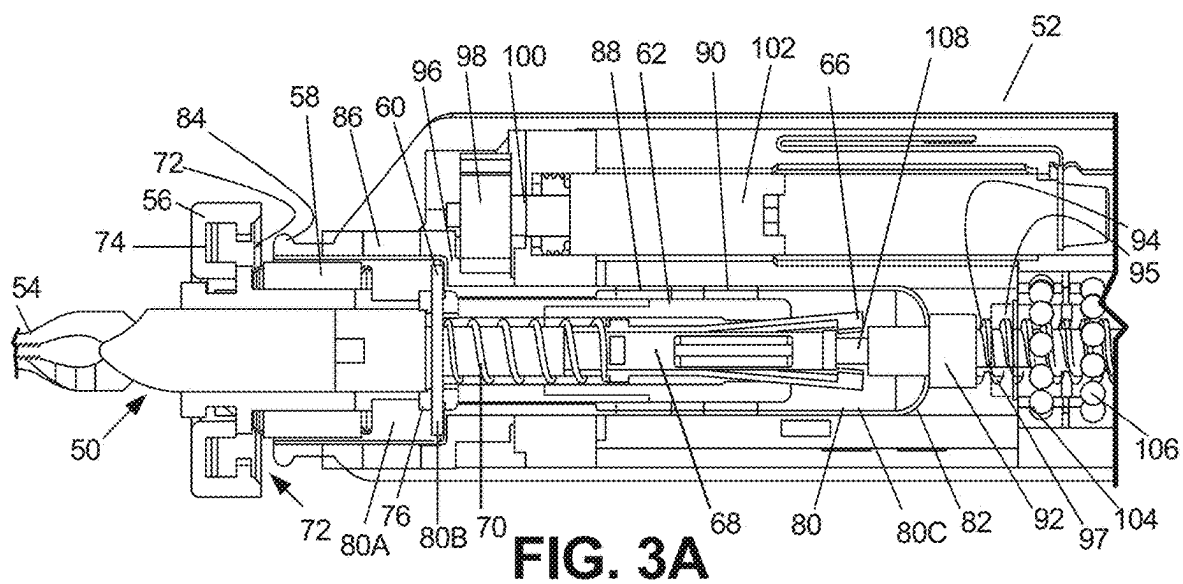
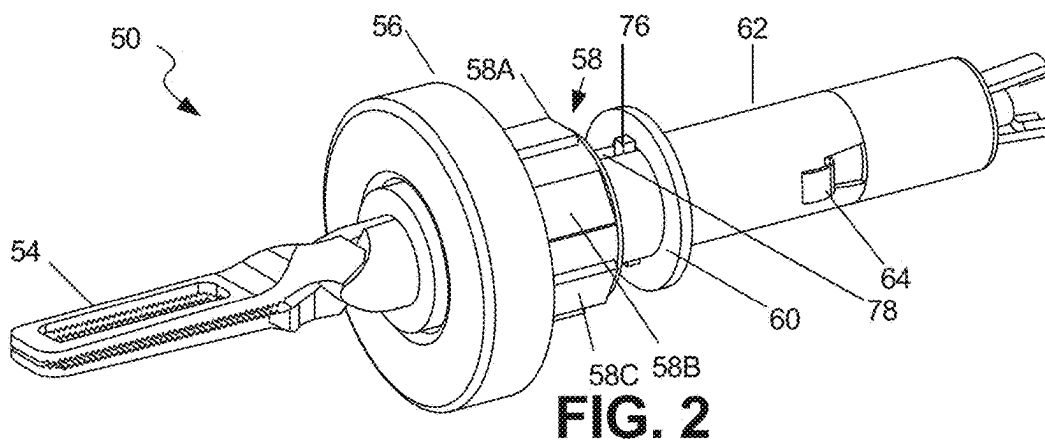
Ishiyama et al., "Spiral-type Micro-machine for Medical Applications," 2000 International Symposium on Micromechatronics and Human Science, 2000: 65-69.

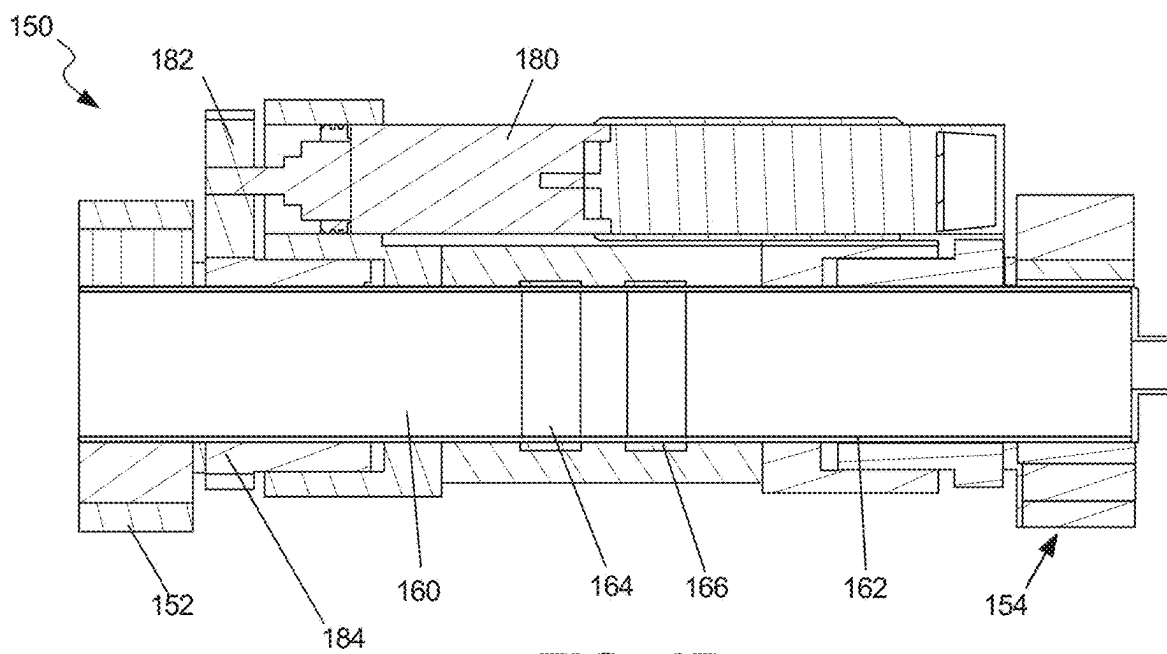
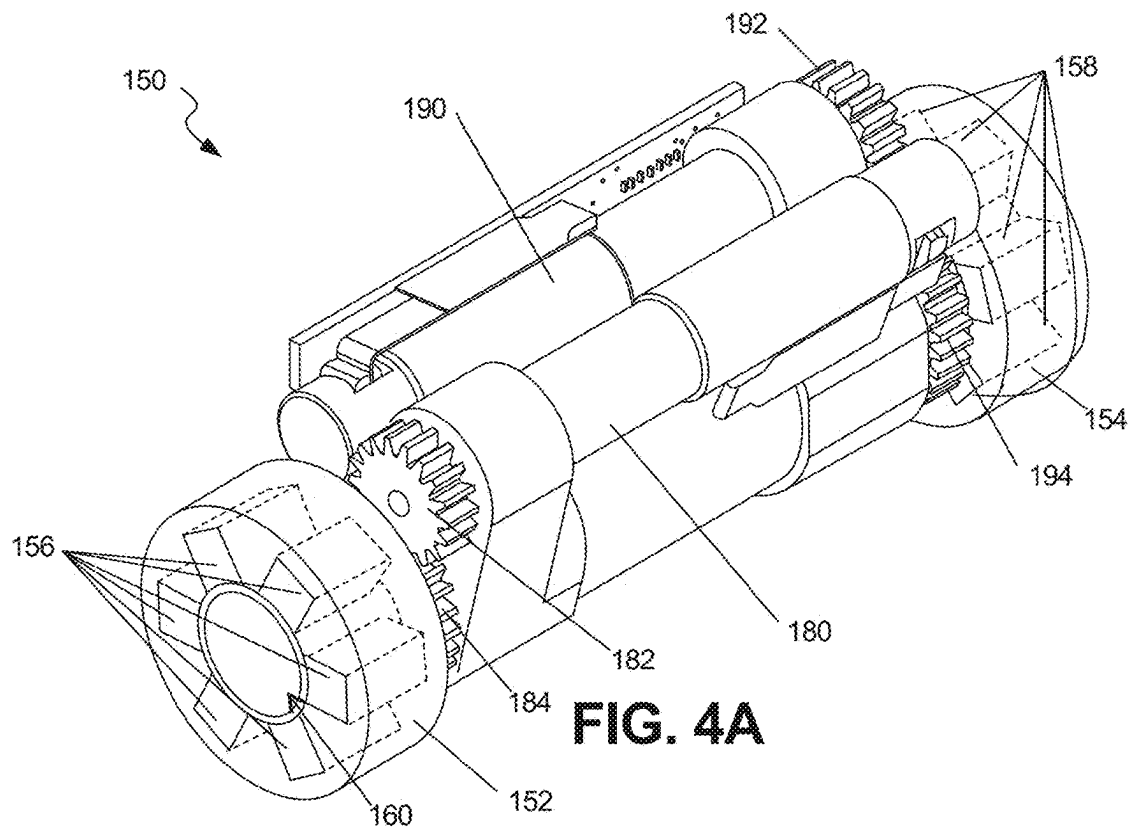
Jagannath et al., "Peroral transgastric endoscopic ligation of fallopian tubes with long-term survival in a porcine model," Gastrointestinal Endoscopy, 2005; 61(3): 449-453.

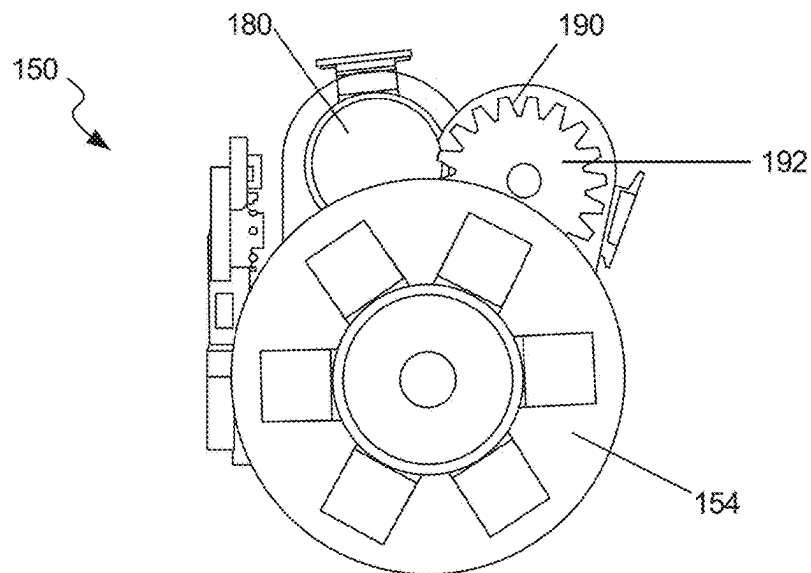
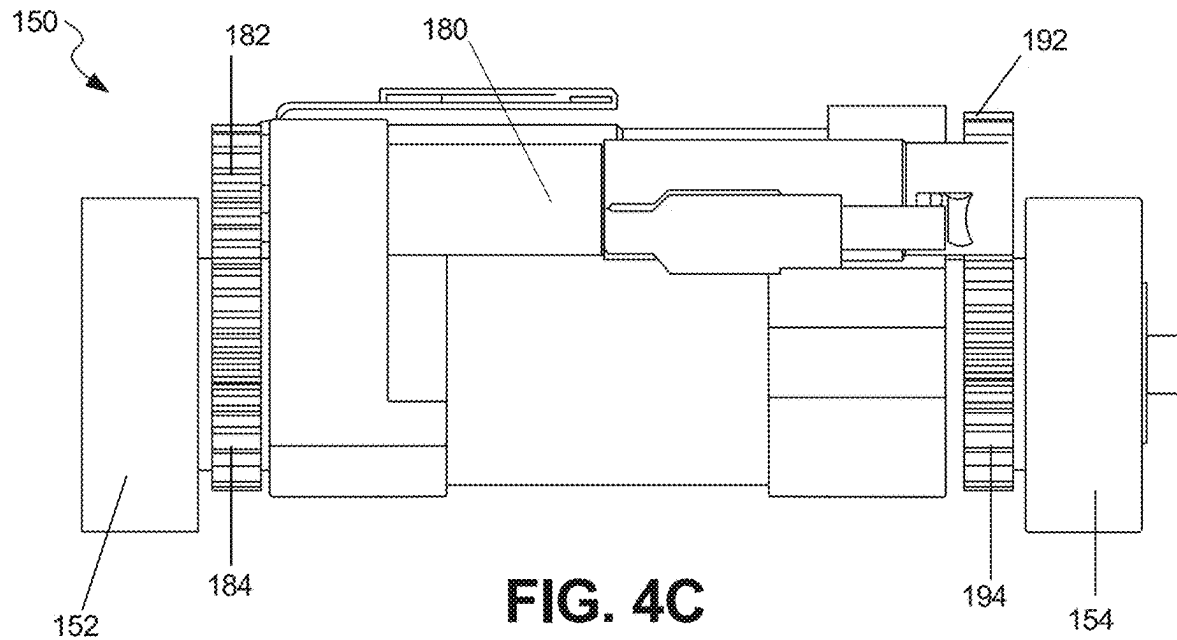
Kaloo et al., "Flexible transgastric peritoneoscopy: a novel approach to diagnostic and therapeutic interventions in the peritoneal cavity," Gastrointestinal Endoscopy, 2004; 60(1): 114-117.

* cited by examiner









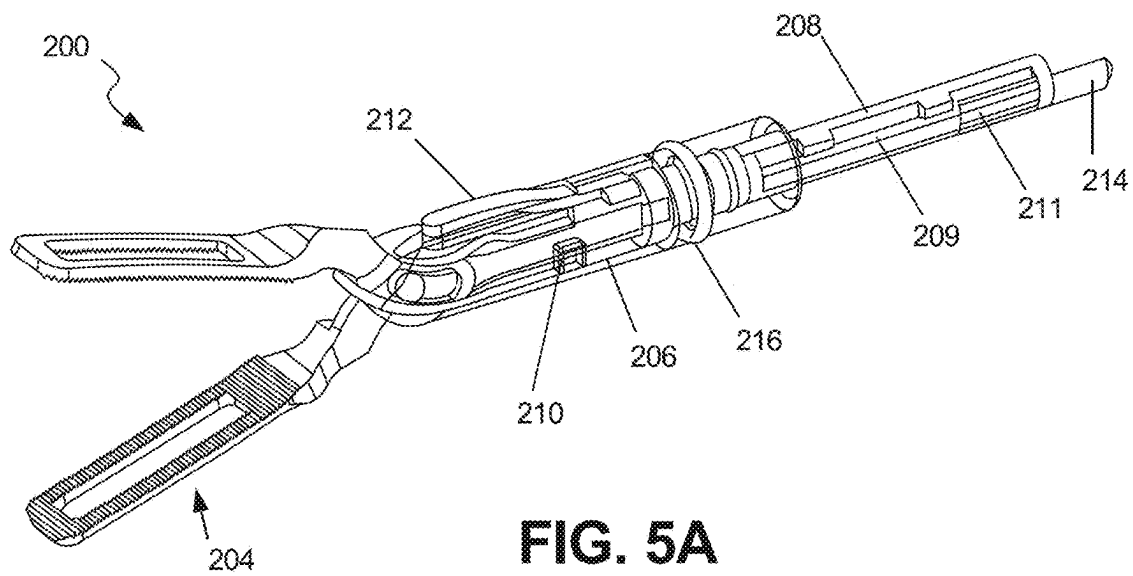


FIG. 5A

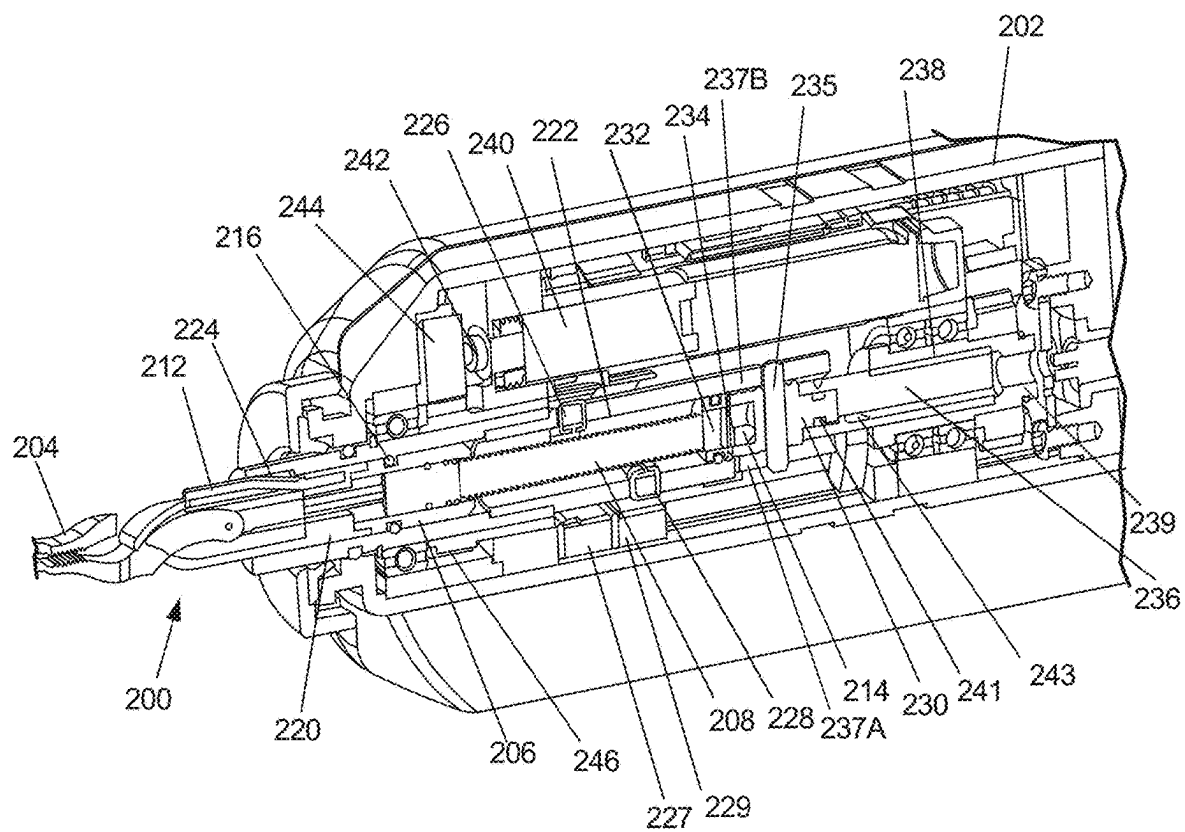


FIG. 5B

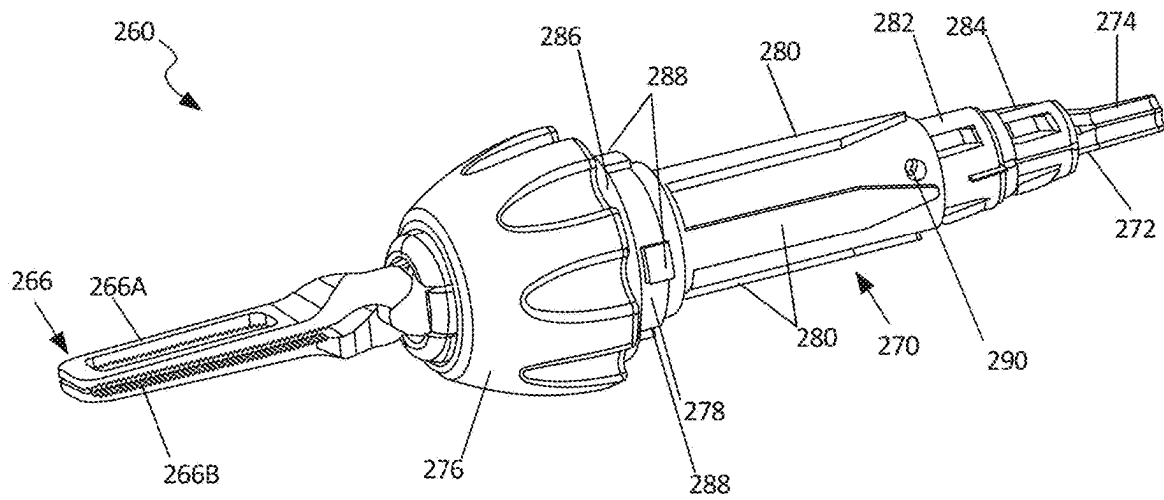


FIG. 6

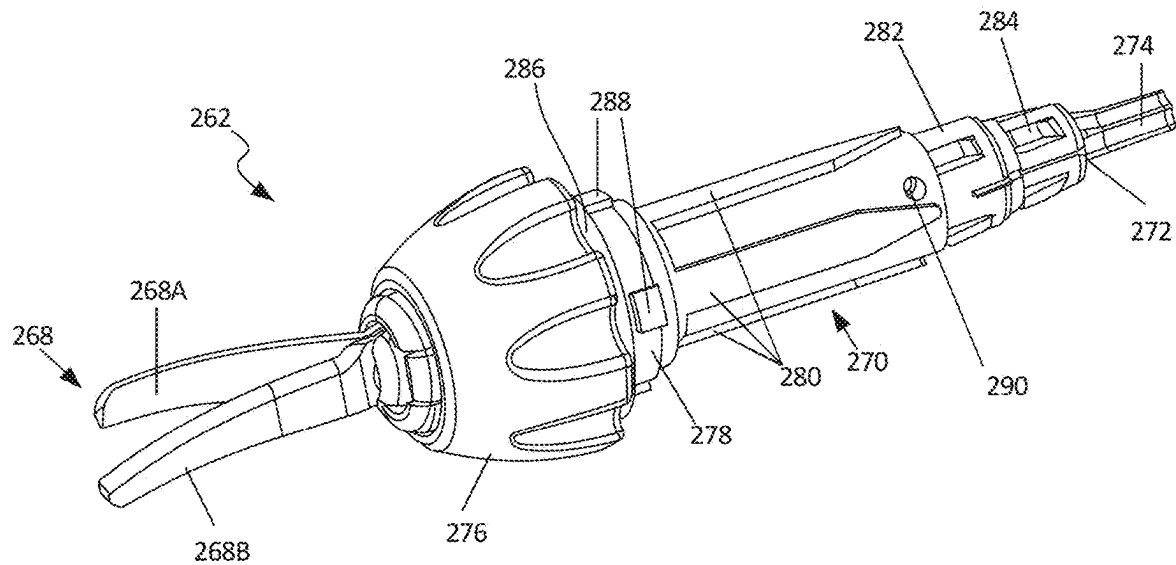
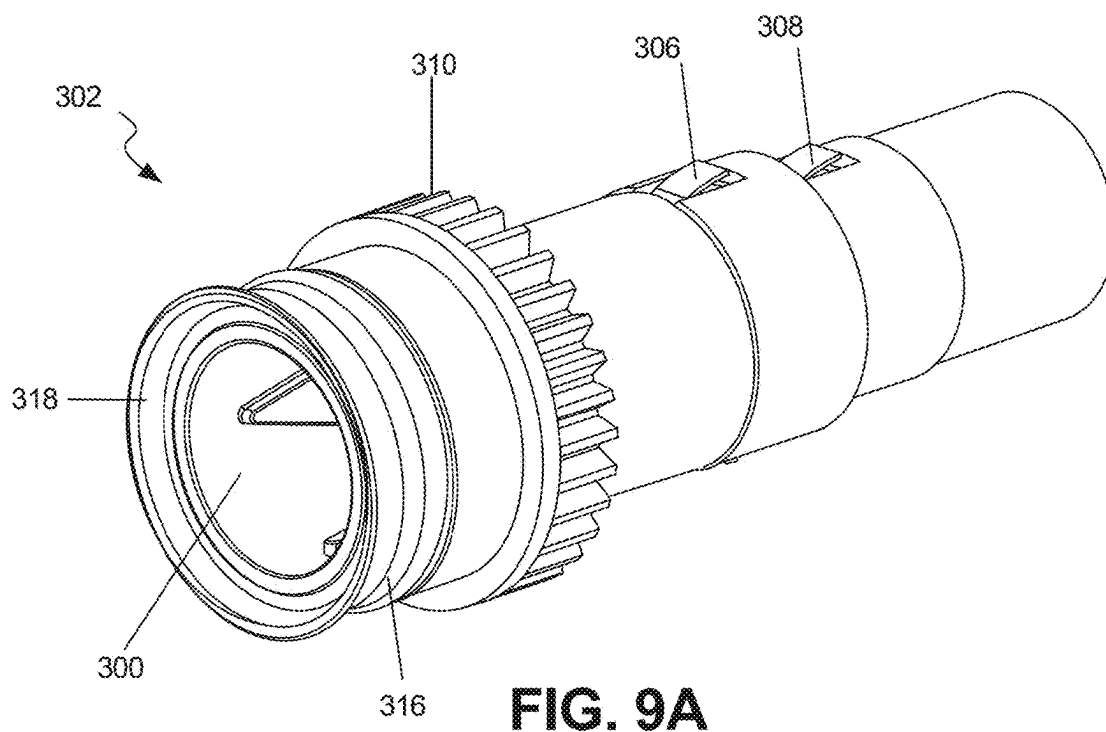
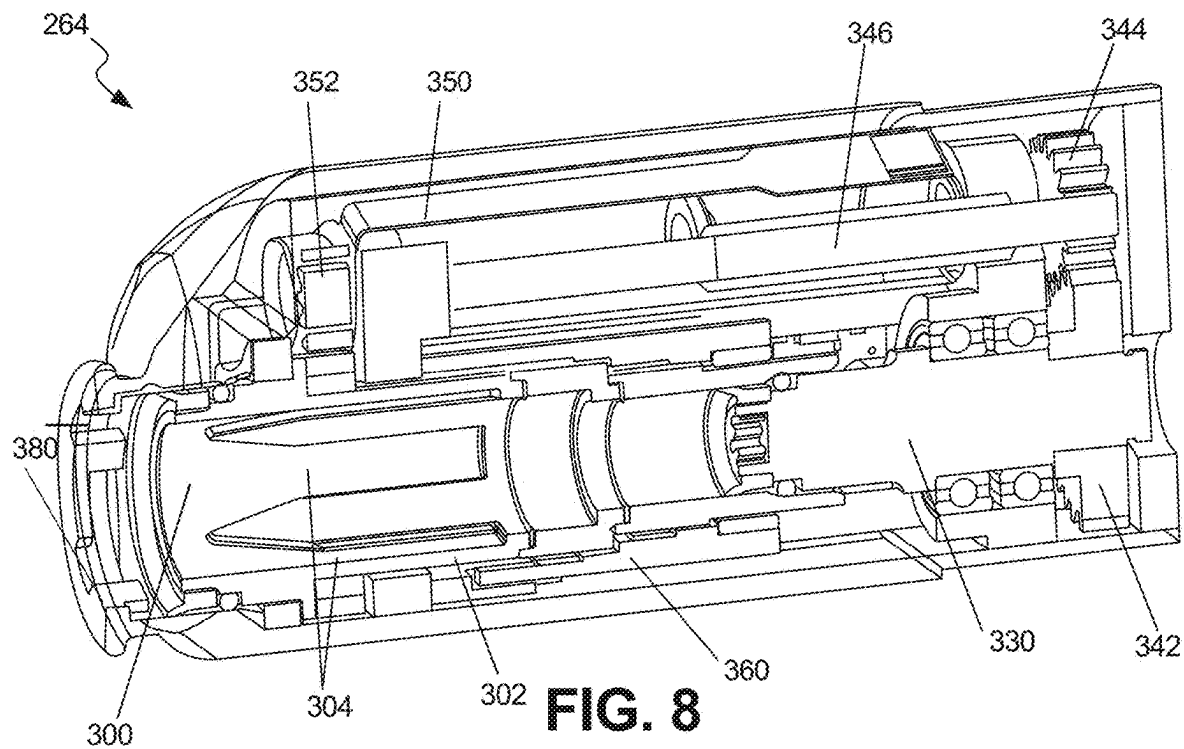
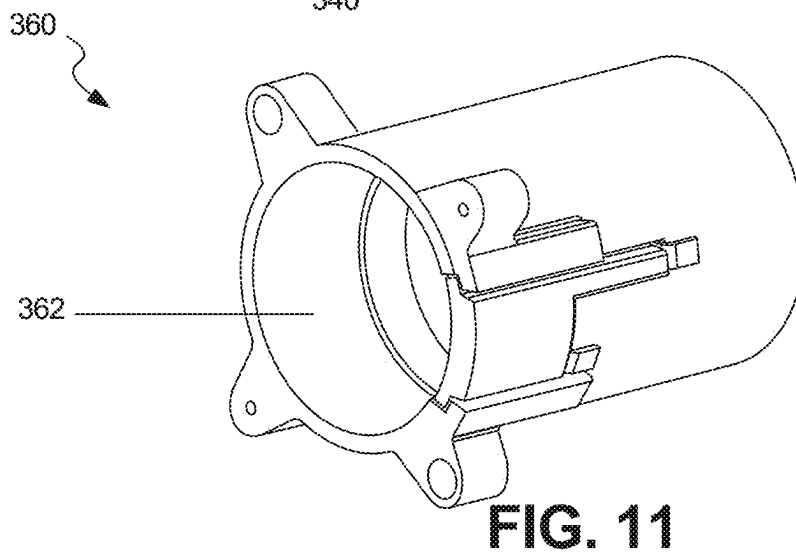
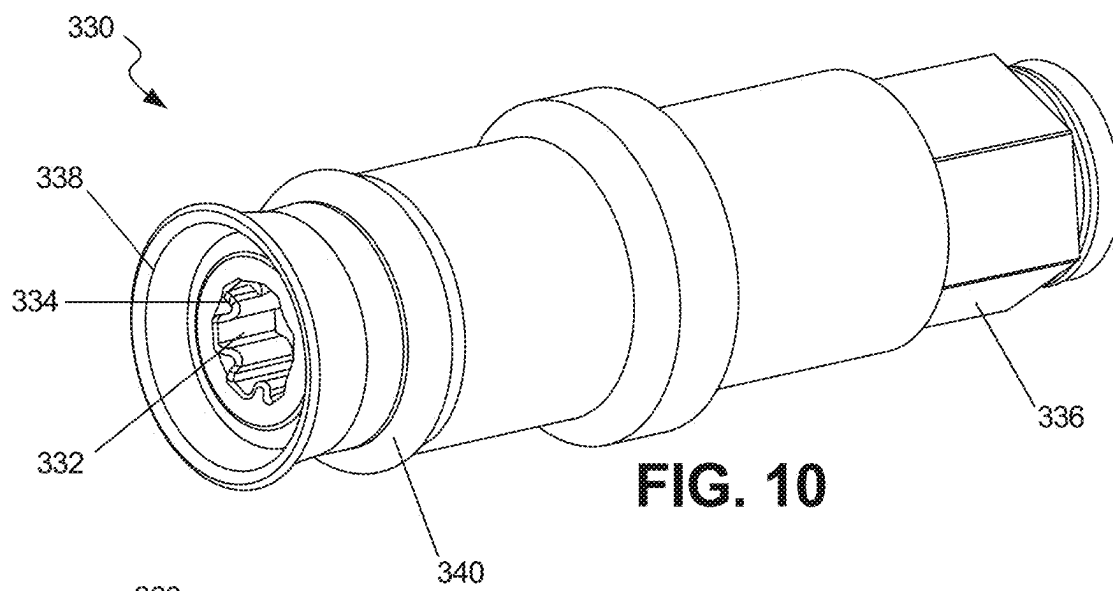
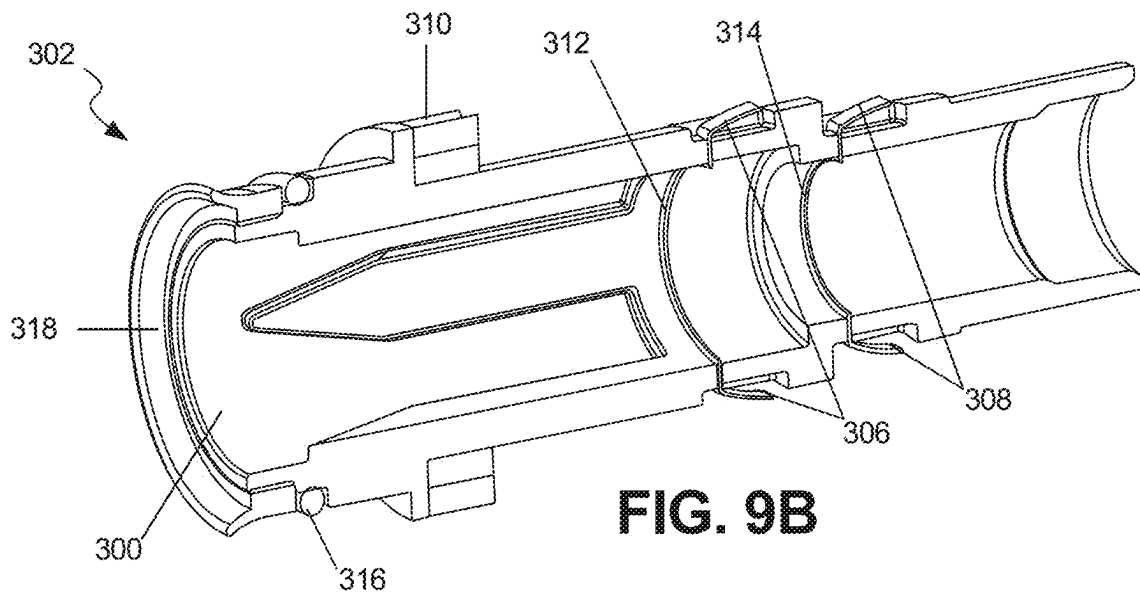
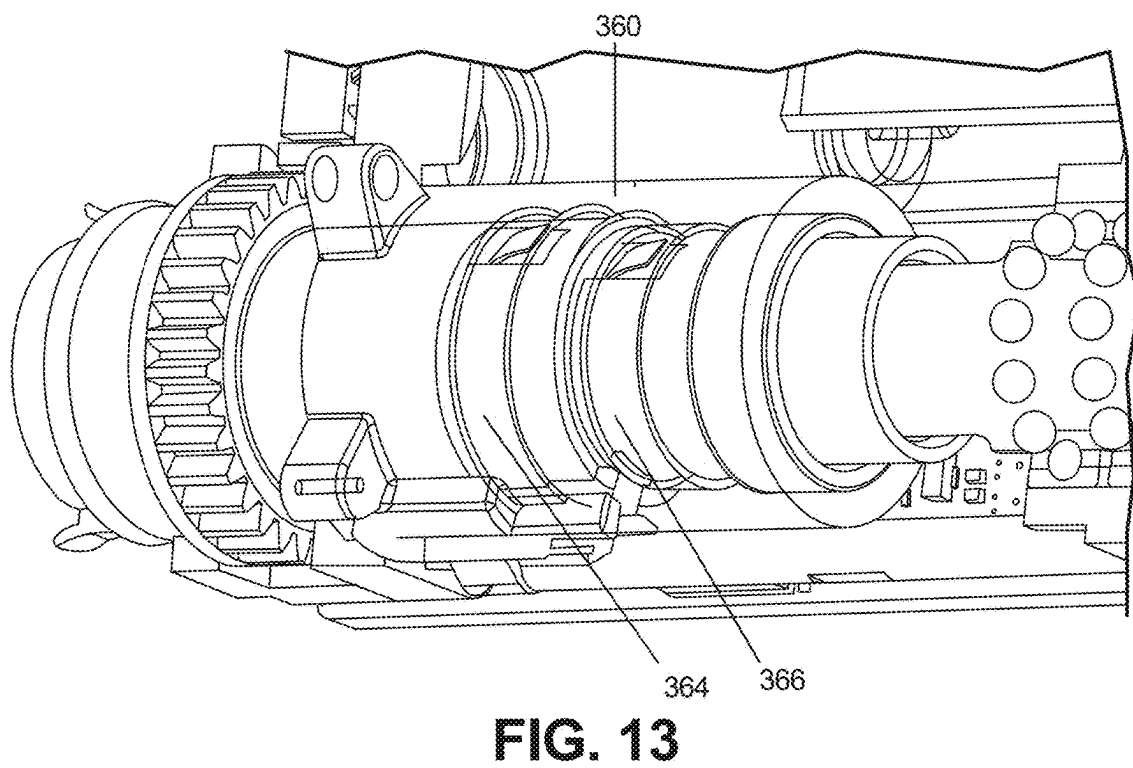
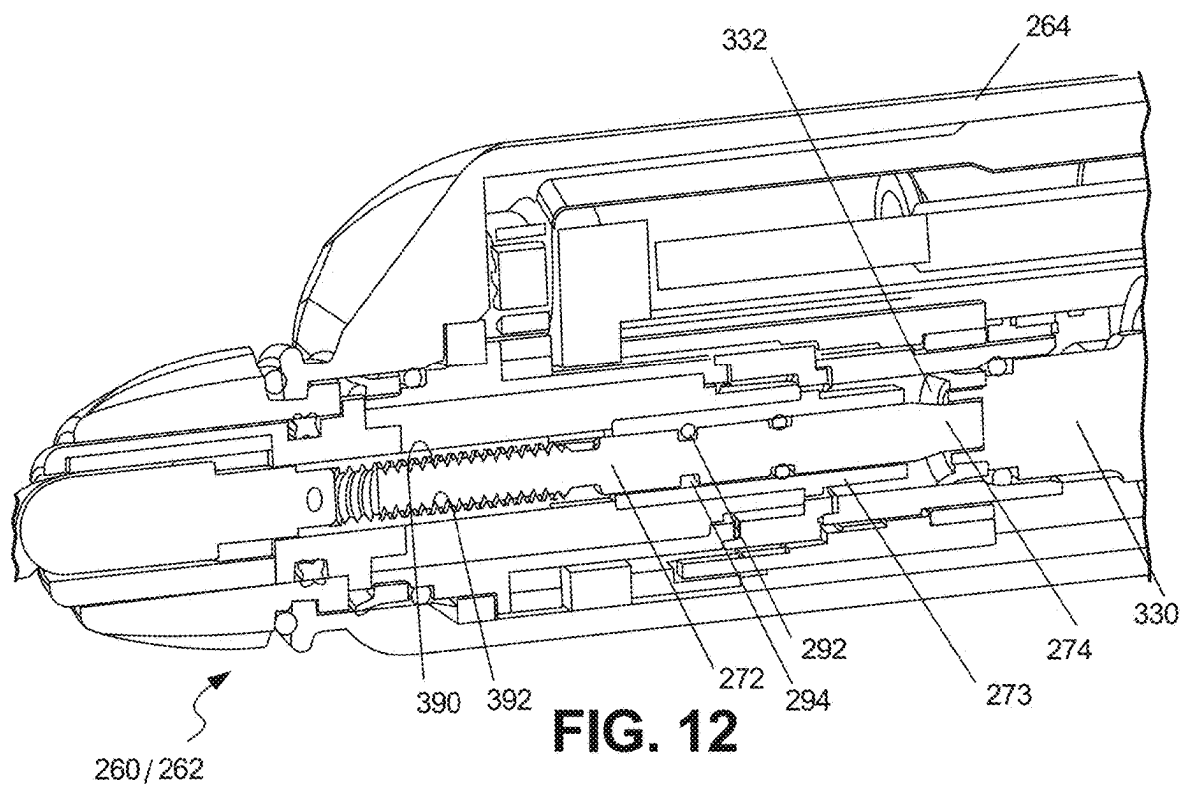
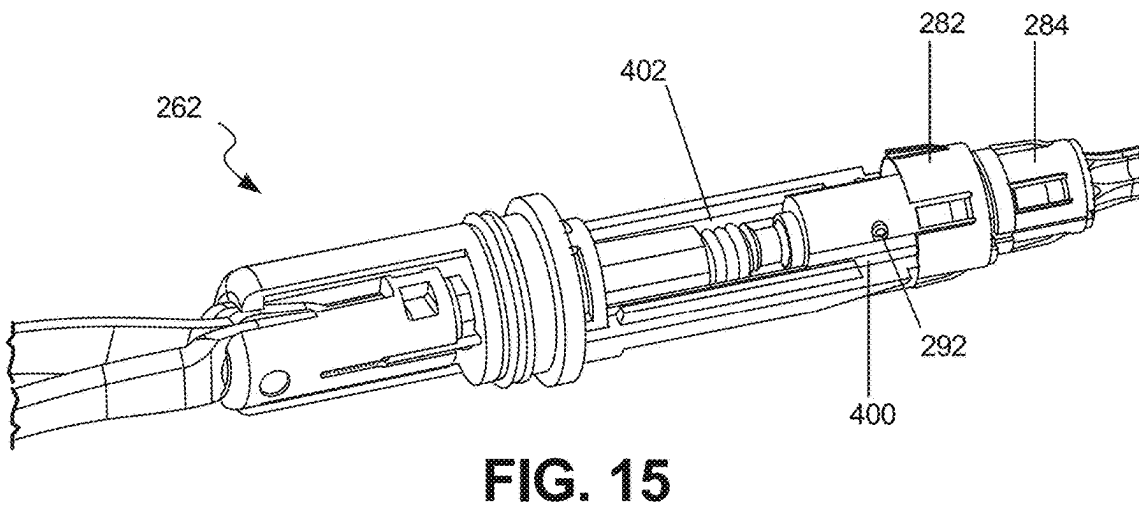
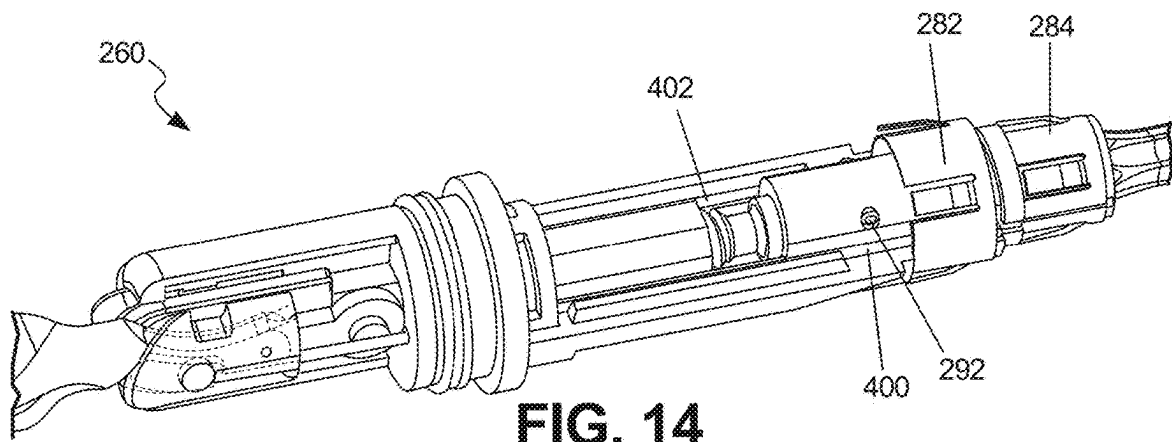


FIG. 7









QUICK-RELEASE END EFFECTORS AND RELATED SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATION

This patent application claims priority as a continuation of U.S. patent application Ser. No. 16/504,793, filed on Jul. 8, 2019, now issued as U.S. Pat. No. 11,576,695 and entitled “Quick-Release End Effectors and Related Systems and Methods,” which claims priority as a continuation of U.S. patent application Ser. No. 14/853,477, filed on Sep. 14, 2015, now issued as U.S. Pat. No. 10,342,561 and entitled “Quick-Release End Effectors and Related Systems and Methods,” which claims the benefit under 35 U.S.C. § 119(e) to U.S. Provisional Application 62/049,419, filed Sep. 12, 2014 and entitled “Quick-Release End Effectors and Related Systems and Methods,” all of which are hereby incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

The various embodiments disclosed herein relate to various medical device systems and related components, including robotic and/or in vivo medical devices and related components. More specifically, certain embodiments include various medical device operational components, often referred to as “end effectors.” Certain end effector embodiments disclosed herein relate to quick-release end effectors that can be easily coupled to and removed from a medical device—including the forearm of a robotic medical device—with ease and efficiency. Further embodiments relate to systems and methods for operating the above components.

BACKGROUND OF THE INVENTION

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures, such as laparoscopy, are preferred. However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to the need to remove and insert new surgical tools into the body cavity when changing surgical instruments due to the size of the access ports. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, CA) are also restricted by the access ports and trocars, the necessity for medical professionals to remove and insert new surgical tools into the abdominal cavity, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

Various robotic surgical tools have been developed to perform certain procedures inside a target cavity of a patient. These robotic systems are intended to replace the standard laparoscopic tools and procedures—such as, for example, the da Vinci® system—that involve the insertion of long surgical tools through trocars positioned through incisions in the patient such that the surgical tools extend into the target cavity and allow the surgeon to perform a procedure using the long tools. As these systems are developed, various new components are developed to further improve the operation and effectiveness of these systems.

There is a need in the art for improved end effectors for use with medical devices, including robotic surgical systems.

BRIEF SUMMARY OF THE INVENTION

Discussed herein are various arms or forearms of medical devices that are configured to receive quick-release end effectors. Further embodiments relate to such quick-release end effectors. Additional implementations relate to arms or forearms of medical devices coupled to such quick-release end effectors.

In Example 1, an arm component for a medical device comprises an arm body, a rotatable cylinder disposed within the arm body, and a rotatable linear drive component operably coupled to the rotatable cylinder. The rotatable cylinder comprises a fluidically sealed end effector lumen defined within the rotatable cylinder and at least one torque transfer channel defined in a wall of the end effector lumen. The rotatable linear drive component comprises a rotatable body, and a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises mating features defined within the drive component lumen.

Example 2 relates to the arm component according to Example 1, further comprising a ring seal disposed between the arm body and the rotatable cylinder.

Example 3 relates to the arm component according to Example 1, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.

Example 4 relates to the arm component according to Example 1, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a driven gear operably coupled to the linear drive component, wherein actuation of the second motor causes rotation of the linear drive component.

Example 5 relates to the arm component according to Example 1, further comprising a first outer contact ring disposed around the rotatable cylinder, a second outer contact ring disposed around the rotatable cylinder, a first contact component disposed on an outer wall of the rotatable cylinder such that the first contact component is in continuous contact with the first inner contact ring regardless of a rotational position of the rotatable cylinder, a second contact component disposed on the outer wall of the rotatable cylinder such that the second contact component is in continuous contact with the second inner contact ring regardless of the rotational position of the rotatable cylinder, a first inner contact ring disposed on the inner wall of the end effector lumen, and a second inner contact ring disposed on the inner wall of the end effector lumen.

Example 6 relates to the arm component according to Example 5, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising first and second end effector contact components, wherein the first end effector contact component is in contact with the first inner contact ring and the second end effector contact component is in contact with the second inner contact ring when the quick-release end effector is operably coupled to the arm.

Example 7 relates to the arm component according to Example 1, further comprising a quick-release end effector configured to be positionable within the end effector lumen. The quick-release end effector comprises an end effector body, at least one torque transfer protrusion defined in an exterior portion of the end effector body, a rod disposed within the end effector body, and a rod coupling component disposed at a proximal portion of the rod. The at least one

3

torque transfer protrusion is configured to be mateable with the at least one torque transfer channel in the end effector lumen. The rod coupling component is configured to be coupleable with the mating features defined in the lumen of the rotatable linear drive component.

In Example 8, a quick-release end effector for a medical device comprises an end effector body, an end effector coupling component disposed around the end effector body, at least one torque transfer protrusion defined in an exterior portion of the end effector body, a rod disposed within the end effector body, a rod coupling component disposed at a proximal portion of the rod, and first and second contact rings disposed around the rod. The end effector coupling component comprises at least one male protrusion extending from the coupling component. The rod coupling component comprising first mating features disposed on an external portion of the rod coupling component.

Example 9 relates to the quick-release end effector according to Example 8, further comprising an end effector disposed at a distal end of the end effector body, wherein the end effector is operably coupled to the rod such that actuation of the rod causes actuation of the end effector.

Example 10 relates to the quick-release end effector according to Example 8, further comprising a grasper end effector comprising first and second grasper arms, wherein the first contact ring is electrically coupled to the first grasper arm and the second contact ring is electrically coupled to the second grasper arm.

Example 11 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device.

Example 12 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device, the lumen comprising at least one torque transfer channel defined in the lumen, wherein the at least one torque transfer protrusion is configured to be mateable with the at least one torque transfer channel in the end effector lumen.

Example 13 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in a lumen of an arm of a medical device, wherein the arm comprises at least one female channel defined in a distal portion of the arm, wherein the end effector coupling component is configured to be coupleable to the arm such that the at least one male protrusion is mateable with the at least one female channel.

Example 14 relates to the quick-release end effector according to Example 8, wherein the end effector is configured to be positionable in an arm of a medical device. The arm comprises an arm body, a rotatable cylinder disposed within the arm body, and a rotatable linear drive component operably coupled to the rotatable cylinder. The rotatable cylinder comprises an end effector lumen defined within the rotatable cylinder, and at least one torque transfer channel defined in a wall of the end effector lumen. The linear drive component comprises a rotatable body, and a lumen defined in a distal portion of the rotatable body, wherein the lumen comprises second mating features defined within the lumen. The first mating features of the rod coupling component are configured to be coupleable with the second mating features defined within the lumen of the rotatable linear drive component.

In Example 15, an arm component for a medical device comprises a forearm and a quick-release end effector. The forearm comprises a forearm body, a fluidically sealed tube defining an end effector lumen within the forearm body, a

4

magnetic ring disposed around the end effector lumen, and a linear drive component disposed at a proximal end of the end effector lumen. The linear drive component comprises a proximal section comprising external threads and a slot defined in a distal portion of the linear drive component. The quick-release end effector is configured to be positionable within the end effector lumen and comprises an end effector body, a magnetic collar disposed around the end effector body, a rod disposed within the end effector body, and at least one finger component operably coupled to the rod, wherein the at least one finger component extends proximally from the rod and is configured to be coupleable with the slot in the linear drive component.

Example 16 relates to the arm component for a medical device according to Example 15, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to a first driven gear, wherein the driven gear is operably coupled to the magnetic ring, wherein actuation of the first motor causes rotation of the magnetic ring.

Example 17 relates to the arm component for a medical device according to Example 16, wherein the magnetic collar is magnetically coupleable with the magnetic ring such that rotation of the magnetic ring causes rotation of the magnetic collar.

Example 18 relates to the arm component for a medical device according to Example 15, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a drive cylinder, wherein the drive cylinder is operably coupled to the proximal section of the linear drive component, wherein the actuation of the second motor causes axial movement of the linear drive component.

Example 19 relates to the arm component for a medical device according to Example 15, wherein the fluidically sealed tube is fixedly coupled to the linear drive component, wherein the fluidically sealed tube is configured to flex when the linear drive component moves axially.

Example 20 relates to the arm component for a medical device according to Example 15, further comprising a compression spring disposed within the forearm body, wherein the compression spring is operably coupled to the forearm body and the at least one finger.

In Example 21, an arm component for a medical device comprises a forearm comprising a forearm body, a fluidically sealed tube defining an end effector lumen within the forearm body, a first magnetic ring disposed around the end effector lumen at or near the distal end of the forearm body, a first motor operably coupled to a first drive gear, a second magnetic ring disposed around the end effector lumen at or near a proximal end of the forearm body, and a second motor operably coupled to a second drive gear. The lumen comprises an opening defined at a distal end of the forearm body. The first drive gear is operably coupled to a first driven gear, wherein the first driven gear is operably coupled to the first magnetic ring. The second drive gear is operably coupled to a second driven gear, wherein the second driven gear is operably coupled to the second magnetic ring.

In Example 22, an arm component for a medical device comprises a forearm and a quick-release end effector. The forearm comprises a forearm body, a rotatable cylinder disposed within the forearm body, a linear drive component operably coupled to the rotatable cylinder, and a rotatable drive component defining a drive component lumen comprising internal threads. The rotatable cylinder comprises an end effector lumen defined within the rotatable cylinder. The linear drive component comprises a proximal section com-

5

prising external threads, a lumen defined in a distal portion of the linear drive component, and a cylinder coupling pin coupled to the linear drive component. The lumen comprises a hook coupling pin disposed within the lumen. Each end of the cylinder coupling pin is slideably disposed in a longitudinal slot defined in the rotatable cylinder. The drive component lumen is configured to be threadably coupled to the proximal section of the linear drive component. The quick-release end effector is configured to be positionable within the end effector lumen and comprises an end effector body, a rod disposed within the end effector body, and a coupling hook operably coupled to a proximal portion of the rod, wherein the coupling hook extends proximally from the rod and is configured to be coupleable with the hook coupling pin.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a perspective view of a robotic surgical device having arms.

FIG. 1B is a perspective view of another robotic surgical device having arms.

FIG. 1C is a perspective view of a further robotic surgical device having arms.

FIG. 1D is a perspective view of a forearm of a robotic surgical device having a quick-release end effector, according to one embodiment.

FIG. 2 is a perspective view of a quick-release end effector, according to one embodiment.

FIG. 3A is an expanded cross-sectional side view of a portion of the quick-release end effector of FIG. 2 positioned in a portion of a forearm, according to one embodiment.

FIG. 3B is a further expanded cross-sectional side view of the portion of the quick release end effector positioned in the portion of the forearm of FIG. 3A.

FIG. 4A is a perspective view of a quick-release forearm configured to receive a quick-release end effector, according to another embodiment.

FIG. 4B is a cross-sectional side view of the quick-release forearm of FIG. 4A.

FIG. 4C is a side view of the quick-release forearm of FIG. 4A.

FIG. 4D is an end view of the quick-release forearm of FIG. 4A.

FIG. 5A is a perspective view of another quick-release end effector, according to a further embodiment.

FIG. 5B is an expanded cross-sectional perspective view of a portion of the quick-release end effector of FIG. 5A positioned in a portion of a forearm, according to one embodiment.

FIG. 6 is a perspective view of another quick-release end effector, according to yet another embodiment.

FIG. 7 is a perspective view of another quick-release end effector, according to another embodiment.

FIG. 8 is a cross-sectional side view of another quick-release forearm configured to receive a quick-release end effector, according to another embodiment.

6

FIG. 9A is a perspective view of a rotatable cylinder that can define the end effector lumen in the quick-release forearm of FIG. 8, according to one embodiment.

FIG. 9B is a cross-sectional perspective view of the rotatable cylinder of FIG. 9A.

FIG. 10 is a perspective view of a linear drive component that can be positioned in the quick-release forearm of FIG. 8, according to one embodiment.

FIG. 11 is a perspective view of a support cylinder that can be positioned around the rotatable cylinder in the quick-release forearm of FIG. 8, according to one embodiment.

FIG. 12 is a cross-sectional side view of the quick-release forearm of FIG. 8 with a quick-release end effector positioned therein, according to one embodiment.

FIG. 13 is an expanded perspective view of the quick-release forearm of FIG. 8 with certain components removed for easier viewing of certain portions of the forearm.

FIG. 14 is an expanded perspective view of the quick-release end effector of FIG. 6 with certain components removed for easier viewing of certain portions of the end effector.

FIG. 15 is an expanded perspective view of the quick-release end effector of FIG. 7 with certain components removed for easier viewing of certain portions of the end effector.

DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to end effector components or devices that can be used in various procedural devices and systems. For example, certain embodiments relate to quick-release end effector components incorporated into or used with various medical devices, including robotic and/or in vivo medical devices. It is understood that the term “quick-release” as used herein are intended to describe any end effector, forearm, or combination thereof that can be easily and/or quickly coupled and/or uncoupled by anyone in the surgical theater, including any nurse or assistant (in contrast to a component that cannot be coupled or uncoupled quickly or easily or requires someone with technical expertise).

It is understood that the various embodiments of end effector devices or components disclosed herein can be incorporated into or used with any other known medical devices, systems and methods, including, but not limited to, robotic or in vivo devices as defined herein. For example, FIGS. 1A-1D depict certain exemplary medical devices and systems that could incorporate a quick-release end effector as disclosed or contemplated herein. More specifically, FIGS. 1A-1C show robotic surgical devices 10, 12, 14 having arms 16A, 16B, 18A, 18B, 20A, 20B to which certain end effectors 22A, 22B, 24A, 24B, 26A, 26B have been coupled. In one implementation, the end effectors 22A, 22B, 24A, 24B, 26A, 26B are quick-release end effectors as disclosed herein. Further, FIG. 1D depicts a forearm 28 that has a quick-release end effector 30.

As a further example, the various embodiments disclosed herein can be incorporated into or used with any of the medical devices and systems disclosed in copending U.S. application Ser. No. 11/766,683 (filed on Jun. 21, 2007 and entitled “Magnetically Coupleable Robotic Devices and Related Methods”), Ser. No. 11/766,720 (filed on Jun. 21, 2007 and entitled “Magnetically Coupleable Surgical Robotic Devices and Related Methods”), Ser. No. 11/966,

741 (filed on Dec. 28, 2007 and entitled “Methods, Systems, and Devices for Surgical Visualization and Device Manipulation”), 61/030,588 (filed on Feb. 22, 2008), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled “Methods and Systems of Actuation in Robotic Devices”), Ser. No. 12/192,663 (filed Aug. 15, 2008 and entitled “Medical Inflation, Attachment, and Delivery Devices and Related Methods”), Ser. No. 12/192,779 (filed on Aug. 15, 2008 and entitled “Modular and Cooperative Medical Devices and Related Systems and Methods”), Ser. No. 12/324,364 (filed Nov. 26, 2008 and entitled “Multifunctional Operational Component for Robotic Devices”), 61/640,879 (filed on May 1, 2012), Ser. No. 13/493,725 (filed Jun. 11, 2012 and entitled “Methods, Systems, and Devices Relating to Surgical End Effectors”), Ser. No. 13/546,831 (filed Jul. 11, 2012 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), 61/680,809 (filed Aug. 8, 2012), Ser. No. 13/573,849 (filed Oct. 9, 2012 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), Ser. No. 13/738,706 (filed Jan. 10, 2013 and entitled “Methods, Systems, and Devices for Surgical Access and Insertion”), Ser. No. 13/833,605 (filed Mar. 15, 2013 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), Ser. No. 13/839,422 (filed Mar. 15, 2013 and entitled “Single Site Robotic Devices and Related Systems and Methods”), Ser. No. 13/834,792 (filed Mar. 15, 2013 and entitled “Local Control Robotic Surgical Devices and Related Methods”), Ser. No. 14/208,515 (filed Mar. 13, 2014 and entitled “Methods, Systems, and Devices Relating to Robotic Surgical Devices, End Effectors, and Controllers”), Ser. No. 14/210,934 (filed Mar. 14, 2014 and entitled “Methods, Systems, and Devices Relating to Force Control Surgical Systems”), Ser. No. 14/212,686 (filed Mar. 14, 2014 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), and Ser. No. 14/334,383 (filed Jul. 17, 2014 and entitled “Robotic Surgical Devices, Systems, and Related Methods”), and U.S. Pat. No. 7,492,116 (filed on Oct. 31, 2007 and entitled “Robot for Surgical Applications”), U.S. Pat. No. 7,772,796 (filed on Apr. 3, 2007 and entitled “Robot for Surgical Applications”), and U.S. Pat. No. 8,179,073 (issued May 15, 2011, and entitled “Robotic Devices with Agent Delivery Components and Related Methods”), all of which are hereby incorporated herein by reference in their entireties.

In accordance with certain exemplary embodiments, any of the various embodiments disclosed herein can be incorporated into or used with a natural orifice transluminal endoscopic surgical device, such as a NOTES device. Those skilled in the art will appreciate and understand that various combinations of features are available including the features disclosed herein together with features known in the art.

Certain device implementations disclosed in the applications listed above can be positioned within or into a body cavity of a patient, including certain devices that can be positioned against or substantially adjacent to an interior cavity wall, and related systems. An “in vivo device” as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned into or within a body cavity of a patient, including any device that is positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms “robot,” and “robotic device” shall refer to any device that can perform a task either automatically or in response to a command.

Further, the various end effector embodiments could be incorporated into various robotic medical device systems that are actuated externally, such as those available from Apollo Endosurgery, Inc., Hansen Medical, Inc., Intuitive Surgical, Inc., and other similar systems, such as any of the devices disclosed in the applications that are incorporated herein elsewhere in this application. Alternatively, the various end effector embodiments can be incorporated into any medical devices that use end effectors.

FIGS. 2-3B depict a quick-release, magnetically-coupled end effector **50** that is releasably coupleable to forearm **52**, according to one embodiment. As best shown in FIG. 2, the end effector **50** in this implementation has a grasper **54**. As best shown in FIGS. 2 and 3A, the end effector **50** also has a mateable coupler **56**, a magnetic collar **58**, a disk **60**, a central rod **68**, a body (also referred to herein as a “forearm body”) **62** that is a slidable cylinder **62** slidably disposed over the rod **68**, a compression spring **70** disposed within the cylinder **62** and over the rod **68**, two leaf springs (one leaf spring **64** is visible in FIG. 2, while the second leaf spring is positioned on the other side of the cylinder **62** and thus not shown in the figure), and coupling fingers (also referred to as “finger components” or “coupling components”) **66**. As best shown in FIGS. 3A and 3B, the mateable coupler **56** has an opening **72** on its proximal side that is configured to receive and be mateable with the coupling projection **84** on the distal end of the forearm **52** (discussed further below). The opening **72** according to one embodiment can contain an o-ring **74** as best shown in FIGS. 3A and 3B that can maintain a sealed connection between the coupler **56** and the projection **84** of the forearm **52**. In one implementation, the magnetic collar **58** is made up of multiple magnets **58A**, **58B**, **58C** as shown that are positioned on the collar around the full circumference of the end effector **50**.

The disk **60** is fixedly coupled to the central rod **68** via a connection tab **76** that is positioned in a slot **78** (as best shown in FIG. 2) in the slidable cylinder **62** such that the cylinder **62** is slidable in relation to the disk **60** as well as the central rod **68**. As such, the disk **60**, as will be described in further detail below, can serve as an axial constraint during insertion of the end effector **50** into the forearm **52** and as a bearing during rotation of the end effector **50** in relation to the forearm **52**.

The first leaf spring **64** is electrically connected to one of the blades of the grasper **54** via a wire or other electrical connection (not shown), while the second leaf spring (not shown) is electrically connected to the other of the two blades of the grasper **54** in the same or a similar fashion. In this implementation, the blades of the grasper **54** are electrically isolated from each other. As such, the graspers **54** can be a cautery tool with electrical energy being transferred to the grasper **54** blades via the leaf springs **64**, not shown, as explained in further detail below.

The two finger components **66** are positioned on opposite sides of the central rod **68** and are attached to the rod **68** at the distal end of the fingers **66** (or along a distal portion of the fingers **66**) such that the fingers **66** do not move axially in relation to the rod **68**. The proximal ends of the fingers **66** extend proximally farther than the rod **68** and are not coupled to the rod at their proximal ends, thereby allowing the proximal ends of the fingers **66** to be capable of extending radially away from the rod **68**. The cylinder **62** is slidable laterally along the length of the end effector **50**, and more specifically along the length of the central rod **68**, such that the cylinder **62** can operate in combination with the

coupler 56 and the coupling fingers 66 as will be discussed in further detail below to couple the end effector 50 to the forearm 52.

In one implementation, the forearm 52 has an end effector lumen 80 defined by a fluidically impervious tube 82 such that the lumen 80 is fluidically sealed. As a result, the internal components of the forearm 52 are fluidically sealed off from any fluids present in the lumen 80. As such, the lumen 80 is capable of receiving an end effector (such as end effector 50) while maintaining a complete fluidic or hermetic seal between the lumen 80 (and any fluids in the lumen 80) and the interior portions of the forearm 52. In this implementation, the fluidic seal created by the tube 82 makes it possible to quickly remove and replace any end effector (such as end effector 50) without risking contamination of the interior components of the forearm 52.

The lumen 80, in one embodiment, has a shoulder 80B that separates a larger diameter portion 80A from a smaller diameter portion 80C. The tube 82 is positioned in the lumen 80 such that the tube 82 defines the lumen 80. In one implementation, the tube 82 is fixedly coupled or affixed to the linear drive component 92 at a proximal end of the tube 82 as best shown in FIG. 3A. In accordance with one embodiment, the tube 82 is made of a flexible material such that when the linear drive component 92 is moved laterally as described below, the tube 82 remains attached to the drive component 92 and simply flexes or deforms to accommodate the movement of the drive component 92.

Further, the forearm 52 has a coupling projection 84 (discussed above), a magnetic ring 86, and two contact rings 88, 90. In addition, the forearm 52 has a linear drive component 92 that has a threaded proximal shaft 94 and a slot 108 defined in a distal portion of the component 92. Alternatively, the threaded shaft 94 is a separate component operably coupled to the linear drive component 92. The forearm 52 also has a drive cylinder 95 having a threaded lumen (not shown) through which the threaded shaft 94 is positioned such that the threaded shaft 94 is threadably coupled to the drive cylinder 95. In addition, two bearings 104, 106 are disposed around the drive cylinder 95 such that the drive cylinder 95 is rotatably positioned within the bearings 104, 106.

Each of the contact rings 88, 90 is positioned around the wall of the tube 82 of the lumen 80 such that each ring 88, 90 encircles the lumen 80. One of the contact rings 88, 90 is positioned along the length of the lumen 80 such that it is in contact with the leaf spring 64 when the end effector 50 is coupled to the forearm 52 as shown in FIG. 3B, while the other of the two contact rings 88, 90 is positioned such that it is in contact with the other leaf spring (not shown). In this configuration, once the end effector 50 is coupled to the forearm 52, the leaf springs (64, not shown) are continuously in contact with the contact rings 88, 90, even when the forearm body 62 is rotating. Further, each of the contact rings 88, 90 is operably coupled to a separate wire (not shown) that extends to an electrical energy source (such as a cautery generator, for example) such that electrical energy can be transmitted from the power sources to the rings 88, 90 and—via the contact between the rings 88, 90 and the leaf springs (64, not shown)—to the leaf springs (64, not shown), and thereby to the grasper 54 blades. As a result, the grasper 54 can be a bipolar cautery tool. Alternatively, the end effector 50 can also be a monopolar cautery tool if the same electrical energy is supplied to both contact rings 88, 90. In fact, as will be discussed specifically with certain of the additional embodiments below, every forearm implementation disclosed or contemplated herein is configured to

be coupleable with a cautery end effector that can operate as either a bipolar or monopolar cautery tool.

The magnetic ring 86 is made up of at least one magnet, and the ring is configured to rotate around the lumen 80. The end effector 50 is rotated via the magnetic interaction of the magnetic collar 58 on the end effector 50 and the magnetic ring 86 on the forearm 52. That is, the motor 102 in the forearm 52 can be actuated to drive the drive gear 98, which drives the driven gear 96, which is operably coupled to the magnetic ring 86 such that the magnetic ring 86 is rotated. The magnetic ring 86 is magnetically coupled to the magnetic collar 58 such that rotation of the magnetic ring 86 causes the magnetic collar 58 to rotate, thereby rotating the end effector 50. That is, the magnetic coupling of the magnetic ring 86 in the forearm 52 and the magnetic collar 58 on the end effector 50 can cause the rotation of the end effector 50 without a physical connection between the end effector 50 and the forearm 52.

In addition, the end effector 50 is actuated such that the grasper 54 moves between an open position and a closed position via the linear drive component 92. The end effector 50 is coupled to the linear drive component 92 via the coupling fingers 66, which are positioned around the drive component 92 and into a slot 108 defined in the drive component 92 as shown in FIGS. 3A and 3B. That is, the fingers 66 extend proximally beyond the proximal end of the central rod 68 and thus the proximal ends of the fingers 66 can be positioned into the slot 108 as shown. The coupling of the drive component 92 to the end effector 50 via the coupling fingers 66 results in the end effector 50 being linearly coupled to the linear drive component 92 such that the end effector 50 cannot move linearly in relation to the drive component 92. On the other hand, the coupling fingers 66 do allow the end effector 50 to rotate in relation to the drive component 92. That is, the fingers 66 are configured to allow for rotation of the fingers 66 in relation to the linear drive component 92 while not allowing for linear movement of the fingers 66 in relation to the linear drive component 92 when the fingers 66 are positioned in the slot 108 as shown in FIG. 3B. Alternatively, instead of coupling fingers 66, the coupling component 66 consists of any one or more mechanisms or components that are configured to be positioned within the slot 108 as described herein to couple the drive component 92 to the end effector 50.

As a result, the actuation of the linear drive component 92 causes the end effector 50 to be actuated to move linearly. That is, as discussed above, the threaded shaft 94 is threadably coupled at its proximal end to a drive cylinder 95 that can be actuated to cause the threaded shaft 94 to move axially. More specifically, the drive cylinder 95 is operably coupled to a drive gear (not shown) that is operably coupled to a motor (not shown) that can be actuated to rotate the drive gear and thereby rotate the drive cylinder 95. The rotation of the drive cylinder 95 causes the threaded shaft 94 to move axially via the threaded connection between the drive cylinder 95 and the threaded shaft 94. The threaded shaft 94 is configured such that it cannot be rotated. That is, the threaded shaft 94 has a slot 97 defined longitudinally in the shaft 94 such that a projection (also referred to as a “tongue” or “key”) (not shown) coupled to the forearm 52 can be positioned in the slot 97, thereby preventing the threaded shaft 94 from rotating while allowing the threaded shaft 94 to move axially. The linear drive component 92 is coupled to the threaded shaft 94 such that rotation of the drive cylinder 95 causes the threaded shaft 94 to move axially, thereby causing the linear drive component 92 to move axially. Thus, actuation of the drive cylinder 95 by the

11

motor (not shown) causes linear movement of the threaded shaft **94** and the linear drive component **92**, thereby causing linear movement of the central rod **68**, which results in the moving of the grasper **54** between an open configuration and a closed configuration via known grasper components for accomplishing the movement between those two configurations.

The end effector **50** is configured to be easily coupled to and uncoupled from the forearm **52** such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. As shown in FIG. **3A**, the end effector **50** has been inserted into the lumen **80** but is not yet fully coupled to the forearm **52**. That is, in FIG. **3A**, the end effector **50** has been inserted into the lumen **80** such that the central rod **68** is in contact with the linear drive component **92** and the coupling fingers **66** have been positioned in the slot **108** of the drive component **92**, but the coupler **56** has not yet been coupled to the projection **84**. Note that, in this position (in FIG. **3A**), the slidable cylinder **62** is in its retracted position.

In FIG. **3B**, the coupler **56** has been coupled to the projection **84**, thereby coupling the end effector **50** to the forearm **52** for use. That is, the urging of the coupler **56** proximally toward the forearm **52** urges the entire end effector **50** proximally toward the forearm. However, the disk **60** on the end effector **50** was already in contact with the shoulder **80B** in the lumen **80** in FIG. **3A**, so the disk **60** is restrained by the shoulder **80B** from moving any further into the lumen **80** when the coupler **56** is urged proximally toward the forearm. Thus, the central rod **68**, which is directly coupled to the disk **60** such that the rod **68** cannot move linearly in relation to the disk **60**, also is restrained from moving any further into the lumen **80**. However, the cylinder **62**, which can move linearly in relation to the disk **60** (because the disk **60**, as explained above, is seated in a tab **76** that is slidably positioned in the slot **78** in the cylinder **62**), moves proximally toward the forearm due to the urging of the coupler **56** proximally. This causes the proximal end of the cylinder **62** to move proximally over the coupling fingers **66**, which are positioned in the slot **108**, as best shown in FIG. **3B**. The result is that the cylinder **62** is positioned at least partially over the slot **108**, thereby securing the fingers **66** in the slot **108**, which thereby secures the end effector **50** to the forearm **52**. This also causes the tension spring **70** disposed in the cylinder **62** to be compressed, because it is positioned between a shoulder **110** in the cylinder and tabs **112** at the distal end of the fingers **66**. That is, the proximal advancement of the cylinder **62** as described above causes the shoulder **110** to move proximally toward the tabs **112** on the fingers **66**, thereby causing the spring **70** to be compressed as shown.

It is understood that the end effector **50** can also be removed just as easily. First, the coupler **56** is pulled distally away from the forearm **52**, thereby uncoupling the coupler **56** from the projection **84** as best shown in FIG. **3A**. This removes the restraint placed on the end effector **50**, thereby allowing the compressed spring **70** as shown in FIG. **3B** to urge the cylinder **62** distally toward the grasper **54**. This causes the proximal end of the cylinder **62** to move distally away from the linear drive component **92** and specifically from the slot **108**, thereby freeing the proximal end of the fingers **66** from their position in the slot **108**, as best shown in FIG. **3A**. With the fingers **66** released from the slot **108**, the end effector **50** can be removed from the lumen **80** of the forearm **52**.

It is understood that the end effector **50** can be either bipolar or monopolar. Similarly, any of the other end effector

12

embodiments disclosed or contemplated herein can also be either bipolar or monopolar, except as discussed in detail below with respect to the end effectors **260**, **262** depicted in FIGS. **6-15**.

FIGS. **4A-4D** depict another embodiment of a magnetic coupling forearm **150**, to which a quick-release, magnetically-coupled end effector (not shown) can be attached, according to one embodiment. In this embodiment, the forearm body **150** has two sets of magnets (in contrast to one set of magnets in the previous embodiment shown in FIGS. **2-3B**). The first magnetic ring **152** is positioned at the distal end of the forearm **150** and drives rotation of the end effector (not shown), while the second magnetic ring **154** is positioned at the proximal end of the forearm **150** and drives linear actuation of the end effector (not shown), thereby actuating operation of the end effector. For example, in those embodiments in which the end effector (not shown) is a grasper, the second magnetic ring **154** would actuate opening and closing of the grasper. Both magnetic rings **152**, **154** are each made up of at least one magnet. More specifically, in this exemplary embodiment, the first ring **152** is made up of six magnets **156**, while the second ring **154** is also made up of six magnets **158**. Alternatively, each of the rings **152**, **154** is made up of at least one magnet. In a further alternative, the number of magnets in each ring **152**, **154** can range from 1 to as many magnets that can fit in the ring to accomplish the purposes described herein.

Further, like the previous embodiment (above), the forearm body **150** has an end effector lumen **160** defined by a fluidically impervious tube **162** such that the lumen **160** is fluidically or hermetically sealed, thereby fluidically sealing the internal components of the forearm **150** from any fluids present in the lumen **160**. The tube **162** is positioned in the lumen **160** such that the tube **162** defines the lumen **160**. The lumen **162** contains two contact rings **164**, **166**.

Each ring **152**, **154** is configured to rotate around the lumen **160** and thereby actuate the end effector (not shown) as described above. More specifically, the first magnetic ring **152** is caused to rotate and thereby cause a magnetic collar (not shown) or other magnetic component on the end effector (not shown) to rotate via the magnetic coupling between the ring **152** and the collar (not shown), thereby causing the end effector (not shown) to rotate. Further, the second magnetic ring **154** is caused to rotate and cause a second magnetic collar (not shown) or other magnetic component on the end effector (not shown) to rotate via the magnetic coupling between the two components, thereby actuating the end effector to operate.

Each of the contact rings **164**, **166** is positioned around the wall of the tube **162** of the lumen **160** such that each ring **164**, **166** encircles the lumen **160**. In this embodiment, each of the contact rings **164**, **166** is positioned along the length of the lumen **160** such that each is in contact with one contact component on the end effector (not shown). For example, if an end effector similar to the end effector **50** discussed above and depicted in FIG. **2** were used, the rings **164**, **166** would be positioned to contact the leaf springs (**64**, not shown) of that end effector **50**. Alternatively, the rings **164**, **166** can be configured to contact any contact component on the end effector that is coupled to the forearm **150**. Regardless, the contact rings **164**, **166** make it possible to transmit electrical energy from power sources to the rings **164**, **166** and on to the end effector in a fashion similar to that described above with respect to end effector **50**. As a result, any end effector used with the forearm **150** can be a bipolar

cautery tool or, alternatively, can be a monopolar cautery tool if the same electrical energy is supplied to both contact rings 164, 166.

The first magnetic ring 152 is actuated by a first motor 180, which is operably coupled to a drive gear 182, which is operably coupled to a driven gear 184, which is operably coupled to the first magnetic ring 152. Thus, actuation of the first motor 180 actuates the first magnetic ring 152 to rotate. Similarly, the second magnetic ring 154 is actuated by a second motor 190, which is operably coupled to a drive gear 192, which is operably coupled to a driven gear 194, which is operably coupled to the second magnetic ring 154. Thus, actuation of the second motor 180 actuates the second magnetic ring 154 to rotate.

Thus, in this embodiment, the forearm 150 actuates an end effector (not shown) entirely by magnetic couplings, rather than mechanical couplings. The first magnetic ring 152 rotates the end effector (not shown) via the magnetic interaction between the ring 152 and the corresponding magnetic collar (not shown) or other magnetic component on the end effector (not shown), while the second magnetic ring 154 actuates the end effector (not shown) via the magnetic interaction between the ring 154 and the corresponding magnetic collar (not shown) or other magnetic component on the end effector (not shown).

Hence, the forearm 150 is configured to allow for easy coupling and removal of an end effector (not shown), such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure.

FIGS. 5A and 5B depict another implementation of a quick-release end effector 200 that is releasably coupleable to a forearm 202, according to one embodiment. More specifically, this exemplary implementation is configured to allow for coupling the end effector 200 to the forearm 202 with a single ninety degree turn of the end effector 200 once the end effector 200 is positioned within the lumen 220 of the forearm 202. This embodiment does not utilize magnetic coupling.

As best shown in FIG. 5A, the end effector 200 in this implementation has a grasper 204. The end effector 200 also has a tubular body 206, a rod (also referred to as a “central rod”) 208 that is disposed within, is slidable in relation to, and extends proximally from the tubular body 206, two protrusions (the first protrusion 210 is depicted in FIG. 5A and a second protrusion is not shown), a release button 212, a coupling hook 214 at a proximal end of the central rod 208, and an o-ring 216 disposed around the tubular body 206. In addition, the rod 208 has two contact elements (also referred to as “contact strips”) 209, 211 that are electrically coupled to the blades of the grasper 204 via separate wires or other connection components such that one strip 209 is coupled to one blade and the other strip 211 is coupled to the other blade. The central rod 208 is operably coupled to the grasper 204 such that linear actuation of the central rod 208 in relation to the tubular body 206 causes the grasper 204 to move between its open and closed configurations. The first 210 and second (not shown) protrusions are positioned on opposite sides of the tubular body 206 and are configured to be positioned within corresponding channels in the forearm 202 as described below.

The forearm body 202 has an end effector lumen 220 defined by a rotatable cylinder 222 such that the cylinder 222 defines the lumen 220. The cylinder 222 has a button channel 224 defined in the cylinder 222 to accommodate the release button 212 when the end effector 200 is positioned within the lumen 220, and two contact rings 226, 228. In addition, the cylinder 222 has two longitudinal channels (not

shown) defined on opposite sides of the inner wall of the lumen 220 that are configured to receive the first protrusion 210 (as shown in FIG. 5A) and the second protrusion (not shown) on the end effector 200 such that the protrusions 210 move along the channels as the end effector 200 is inserted into the lumen 220 of the forearm 202. Further, the channels (not shown) both include a substantially ninety degree turn at the proximal end of the channels that results in two axial slots in communication with the longitudinal channels. The axial slots are configured to accommodate the rotation of the end effector 200 as it is coupled to the forearm 202 as described below.

Each of the contact rings 226, 228 is positioned on the cylinder 222 such that a portion of each ring 226, 228 is positioned around the inner wall of the cylinder 222 such that each ring encircles the lumen 220. In this embodiment, each of the contact rings 226, 228 is positioned along the length of the lumen 220 such that each is in contact with one of the two contact strips 209, 211 on the rod 208 when the end effector 200 is coupled to the forearm 202 as shown in FIG. 5B. More specifically, the contact ring 226 contacts contact strip 209 while contact ring 228 contacts contact strip 211. In this configuration, once the end effector 200 is coupled to the forearm 202, the contact strips 209, 211 are continuously in contact with the contact rings 226, 228, even when the rod 208 is rotating or moving axially. That is, the strips 209, 211 are configured to have some longitudinal length as shown in FIG. 5A such that when the rod 208 is actuated to move axially while coupled to the forearm 202, the strips 209, 211 remain in contact with the contact rings 226, 228 despite the fact that the rings 226, 228 do not move axially.

Further, each of the contact rings 226, 228 is in contact with a stationary contact ring 227, 229 disposed in the forearm 202 such that they encircle the cylinder 222. In addition to being positioned such that a portion is disposed around the inner wall of the cylinder 222, each of the rings 226, 228 also has a portion that is disposed around the external wall of the cylinder 222 such that each ring 226, 228 contacts one of the two stationary contact rings 227, 229 as well. Thus, electrical energy can be transmitted from the power sources to the stationary contact rings 227, 229 and—via the contact between the stationary rings 227, 229 and the contact rings 226, 228—to the contact strips 209, 211 and thereby to the grasper 204 blades. As a result, the grasper 204 can be a bipolar cautery tool. Alternatively, the end effector 200 can also be a monopolar cautery tool if the same electrical energy is supplied to both stationary contact rings 227, 229.

In addition, the forearm 202 has a linear drive component 230 disposed in a proximal end of the rotatable cylinder 222. The drive component 230 has a lumen 232 defined in its distal end, and the lumen 232 has a coupling pin (also referred to as a “hook coupling pin”) 234 extending from one side of the lumen 232 to the other. The pin 234 is configured to be coupleable with the coupling hook 214 of the end effector 200 as will be described in further detail below. Further, the drive component 230 also has a coupling pin (also referred to as a “cylinder coupling pin”) 235 that extends beyond the outer circumference of the drive component 230 such that the ends of the pin 235 are positioned in slots 237A, 237B defined in the inner wall of the rotatable cylinder 222. The pin 235 is fixedly coupled to the drive component 230. Each of these slots 237A, 237B has a length that extends longitudinally along the length of the rotatable cylinder 222. As a result, this pin 235 is slidably positioned in the slots 237A, 237B such that the drive component 230

15

can be moved linearly but cannot rotate in relation to the rotatable cylinder 222. Thus, any rotation of the drive component 230 causes rotation of the rotatable cylinder 222. This configuration prevents the hook 214 from becoming decoupled from the pin 234. That is, the pin 235 prevents the drive component 230 from rotating in relation to the rotatable cylinder 222, thereby ensuring the hook 214 remains coupled to the pin 234.

Further, the proximal end of the drive component 230 has an externally threaded proximal shaft (also referred to as a linear translation component) 236. Alternatively, the shaft 236 is a separate component operably coupled to the drive component 230, via a retaining ring 241. The retaining ring 241 results in the drive component 230 being capable of rotating in relation to the linear translation component 236. Further, the shaft 236 is prevented from rotating by a groove (not shown) defined in the shaft 236 that mates with a tongue 243. In addition, the shaft 236 is positioned within a lumen 238 in a rotatable linear drive component 239 and is threadably coupled to the internal threads defined in the lumen 238. Thus, when the rotatable drive component 239 is rotated by the linear actuation motor (not shown), the threaded connection of the shaft 236 to the rotatable drive component 239 causes the shaft 236 to move linearly, thereby resulting in the drive component 230 moving linearly as well.

The forearm 202 also has a motor 240 coupled to a drive gear 244 via a drive shaft 242. The drive gear 244 is coupled to a driven gear 246 that encircles and is coupled to the rotatable cylinder 222 such that rotation of the driven gear 246 causes the rotatable cylinder 222 to rotate.

The end effector 200 is rotated via the motor 240 that is operably coupled to the driven gear 246. That is, the motor 240 in the forearm 202 can be actuated to drive the drive gear 244, which drives the driven gear 246, which is operably coupled to the rotatable cylinder 222 as described above such that the rotatable cylinder 222 is rotated. The rotatable cylinder 222 is coupled to the end effector 200 when the end effector 200 is fully seated in the lumen 220 of the forearm 202 such that rotation of the rotatable cylinder 222 causes the end effector 200 to rotate. That is, as best shown in FIG. 5A, the first protrusion 210 and second protrusion (not shown) are positioned in the channels (not shown) in the lumen 220 such that the tubular body 206 is coupled to the cylinder 222 such that the tubular body 206 rotates when the cylinder 222 rotates.

In addition, the end effector 200 is actuated such that the grasper 204 moves between an open position and a closed position via the linear drive component 230. The end effector 200 is coupled to the linear drive component 230 via the coupling hook 214, which is positioned into the lumen 232 of the drive component 230 and around the pin 234 positioned in the lumen 232. That is, during insertion of the end effector 200 into the forearm 202, the hook 214 is positioned into the lumen 232 prior to the substantially ninety degree rotation of the end effector 200 such that the hook 214 extends proximally past the pin 234. Thus, when the end effector 200 is rotated, the hook 214 couples to the pin 234 and thereby couples the end effector 200 to the drive component 230. The coupling of the drive component 230 to the end effector 200 via the hook 214 and pin 234 results in the end effector 200 being linearly coupled to the linear drive component 230 such that the end effector 200 cannot move linearly in relation to the drive component 230.

As a result of the coupling of the hook 214 to the pin 234, the actuation of the linear drive component 230 causes the end effector 200 to be actuated to move linearly. That is, the

16

rotatable linear drive component 239 is coupled at its proximal end to a driven gear 250 that is coupled to a drive gear (not shown), which is coupled to a motor (not shown) that can be actuated to rotate the driven gear 250 and thus the rotatable drive component 239. As discussed above, the threaded section 236 of the linear drive component 230 is positioned in and threadably connected with the lumen 238 in the rotatable drive component 239. As a result, rotation of the drive component 239 causes the linear drive component 230 to move axially. Thus, actuation of the drive component 239 by the motor (not shown) causes linear movement of the linear drive component 230, thereby causing linear movement of the central rod 208, which results in the moving of the grasper 204 between an open configuration and a closed configuration via known grasper components for accomplishing the movement between those two configurations.

The end effector 200 is configured to be easily coupled to and uncoupled from the forearm 202 such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. To insert the end effector 200 into the forearm 202 and couple it thereto as shown in FIG. 5B, the end effector 200 is inserted into the lumen 220 such that the first protrusion 210 and second protrusion (not shown) are positioned in the channels (not shown) in the lumen 220. As the end effector 200 is urged proximally into the lumen 220, the hook 214 will advance proximally until it moves into the lumen 232 and past the pin 234. When the hook 214 can advance proximally no farther, the protrusions 212 (and not shown) are also advanced as far proximally as possible along the channels (not shown). At this point, the user rotates the end effector 200, thereby coupling the hook 214 to the pin 234 and advancing the protrusions 212 (and not shown) along the axial slots described above. Thus, a user can couple the end effector 200 to the forearm 202 via two mechanisms with a single twist or rotation of the end effector 200.

It is understood that the end effector 200 can also be easily removed. The release button 212 on the end effector 200 is operably coupled to the coupling hook 214 such that actuation of the button 212 causes the hook 214 to uncouple from the pin 234. Thus, to remove the end effector 200 from the forearm 202, a user can depress the button 212 and then rotate or twist the end effector 200 (in the opposite direction of that required to couple the end effector 200). The rotation of the end effector 200 moves the protrusions 212 (and not shown) along the axial slots (not shown) so that the protrusions 212 (and not shown) are positioned in the channels (not shown) such that they can move distally along the channels (not shown). At this point, the end effector 200 can be removed from the lumen 220 of the forearm 202.

FIGS. 6-14 depict certain additional embodiments of quick-release end effectors 260, 262 that are releasably coupleable to a forearm 264, according to one embodiment. More specifically, these exemplary implementations are configured to allow for coupling of the end effector 260, 262 to the forearm 264 with a single turn of the end effector 260, 262 once the end effector 260, 262 is positioned within the lumen 300 of the forearm 264.

As shown in FIGS. 6 and 14, the end effector 260 in one implementation has a grasper 266. The end effector 260 also has a tubular body 270, a rod (also referred to herein as a "central rod") 272 that is disposed within and is rotatable in relation to the tubular body 270 and has a rod coupling component 274 that extends proximally from the tubular body 270, a handle 276, an end effector coupling component 278, torque transfer protrusions 280, two contact rings 282, 284, an o-ring 286 adjacent to the handle 276, and a pin hole

290 defined in the tubular body 270. Further, as best shown in FIG. 14, the first contact ring 282 is coupled to a first contact wire 400 that extends from the contact ring 282 to the distal end of the end effector 260, where the wire 400 is operably coupled to a proximal portion of one arm 266A of the grasper 266. Similarly, the second contact ring 284 is coupled to a second contact wire 402 that extends from the ring 284 to the distal end of the end effector 260, where the wire 402 is operably coupled to a proximal portion of the other arm 266B of the grasper 266. Thus, each of the two contact rings 282, 284 is electrically coupled to one of the grasper arms 266A, 266B such that electrical energy can be separately transferred from each of the rings 282, 284 to one of the arms 266A, 266B, thereby resulting in a bipolar grasper 266. The central rod 272 is operably coupled to the grasper 266 such that rotational actuation of the central rod 272 (via the rod coupling component 274) in relation to the tubular body 270 causes the grasper 266 to move between its open and closed configurations. The end effector coupling component 278 has male protrusions 288 that mate with female channels 380 on the forearm such that protrusions 288 can be positioned into the channels 380 and the end effector 260 can be coupled to the forearm 264 with a single twist or rotation of the end effector 260. The torque transfer protrusions 280 are formed or positioned around the tubular body 270 and are configured to be positioned within corresponding torque transfer channels 304 in the forearm 264 as described below such that the end effector 260 is not rotatable in relation to the forearm 264 when the protrusions 280 are seated in the channels 304. Note that the ends of the torque transfer protrusions 280 are tapered to make it easier to align the protrusions 280 with the channels 304. In the embodiment of FIG. 6, there are four protrusions 280 (with three visible in the figure). Alternatively, there can be any other number of protrusions that can be used to couple the end effector 260 to the forearm 264, including one to three protrusions, or five or more protrusions.

In an alternative embodiment, the end effector 262 can have a pair of scissors 268 as shown in FIG. 7. According to one implementation, the other components of this end effector 262 are substantially the same as those of the end effector 260 depicted in FIG. 6 and discussed above. As such, those components are identified with the same reference numbers such that the discussion above applies equally to these components as well. One difference, in certain embodiments, relates to the electrical coupling of the contact rings 282, 284 to the scissor arms 268A, 268B. That is, according to some embodiments, both arms 268A, 268B are electrically coupled to both rings 282, 284, thereby resulting in a monopolar pair of scissors 268 as will be described in further detail below. More specifically, as best shown in FIG. 15, the first contact ring 282 is coupled to a first contact wire 400 that extends from the contact ring 282 to the distal end of the end effector 262, where the wire 400 is operably coupled to a proximal portion of the pair of scissors 268 such that the contact ring 282 is electrically coupled to both arms 268A, 268B of the pair 268. Similarly, the second contact ring 284 is coupled to a second contact wire 402 that extends from the ring 284 to the distal end of the end effector 262, where the wire 402 is operably coupled to a proximal portion of the pair of scissors 268 such that the contact ring 284 is electrically coupled to both arms 268A, 268B of the pair 268. Thus, each of the two contact rings 282, 284 is electrically coupled to both scissor arms 268A, 268B such that electrical energy is transferred from both rings 282, 284 to both arms 266A, 266B, thereby resulting in a monopolar grasper 268.

As shown in FIGS. 8-13, the forearm body 264 has an end effector lumen 300 defined by a rotatable cylinder 302 (as best shown in FIGS. 8, 9A, and 9B) such that the cylinder 302 defines the lumen 300. As mentioned above, the cylinder 302 has torque transfer channels 304, two electrical contact components 306, 308, a rotational gear 310 defined or positioned around an external wall of the cylinder 302, an o-ring 316 disposed around the cylinder, and a seal (a "ring seal" or "lip seal" in this embodiment) 318 disposed around the distal opening of the lumen 300. The torque transfer channels 304 are defined in the cylinder 302 to accommodate the torque transfer protrusions 280 of either end effector 260/262 when that end effector 260/262 is positioned within the lumen 300. The channels 304 are tapered to make it easier to align the protrusions 280 with the channels 304. In this exemplary embodiment, the two electrical contact components 306, 308 are contact leaflets 306, 308 that are electrically coupled to contact rings 312, 314 (as best shown in FIG. 9B) (such that the electrical contact component 306 is coupled to the contact ring 312 and contact component 308 is coupled to the contact ring 314). The contact rings 312, 314 are disposed along the inner wall of the lumen 300 and are positioned along the length of the lumen 300 such that they are configured to be in contact with the contact rings 282, 284 on the end effector 260/262 when the end effector 260/262 is coupled to the forearm 264. In one embodiment as shown in FIG. 9B, the contact leaflet pair 306, 308 extend away from the cylinder 302 in the proximal direction. Alternatively, it is understood that the contact leaflets 306, 308 can extend away from the cylinder 302 in the distal direction. In a further alternative, the contact components 306, 308 can each have any known configuration for a contact component.

As best shown in FIGS. 9A and 9B, the lip seal 318 operates to serve as the primary seal to retain the fluidic seal of the forearm 264, thereby preventing fluid from accessing the forearm 264. The o-ring 316 (as also best shown in FIGS. 9A and 9B), according to one embodiment, can operate to serve as a structural support with respect to the cylinder 302, retaining the cylinder 302 in position in relation to the forearm 264 while allowing the cylinder 302 to rotate. In addition, the o-ring 316 can also operate as a backup to the lip seal 318, thereby providing a fluidic seal that prevents any fluid that gets past the lip seal 318 from accessing the internal components of the forearm 264. Further, according to another implementation, the o-ring 316 can also serve to retain lubricant disposed between the lip seal 318 and the o-ring 316.

Alternatively, instead of seal 318, which extends from the rotatable cylinder 302, the seal (not shown) for retaining the fluidic seal of the forearm 264 can instead extend from an inner lumen of the forearm 264—such as a portion of the forearm 264 proximal to the female channels 380—and contact the rotatable cylinder 302, thereby providing the desired fluidic seal for the forearm 264 as described above.

In addition, the forearm 264 has a rotatable linear drive component 330 disposed in the forearm 264 proximally to the rotatable cylinder 302, as best shown in FIGS. 8 and 10. The drive component 330 has a lumen 332 defined in its distal end (as best shown in FIG. 10), and the lumen 332 has teeth 334 extending from the inner wall of the lumen 332 that are configured to mate with the rod coupling component 274 on the proximal end of the end effector 260/262. Alternatively, the lumen 332 can have any type of structure or mechanism—such as ribs, threads, channels, or the like—for mating with or coupling to the rod coupling component 274. In addition, the drive component 330 has an external

structural feature 336, a seal 338 (such as a “ring seal”), and an o-ring 340. The ring seal 338 and o-ring 40, according to one embodiment, can function in substantially the same fashion as the seal 318 and o-ring 316 discussed above. The external structural feature 336 is an external hexagon 336 as best shown in FIG. 10 that is configured to mate with a driven gear 342 operably coupled with a drive gear 344 that is operably coupled with a motor 346 (as best shown in FIG. 8) such that actuation of the motor 346 causes the rotation of the rotatable drive component 330.

Alternatively, instead of ring seal 338, which extends from the linear drive component 330, the seal (not shown) for retaining the fluidic seal can instead extend from the lumen 300 of the rotatable cylinder 302 and contact the rotatable linear drive component 330, thereby providing the desired fluidic seal.

When the end effector 260/262 is coupled to the forearm 264 as best shown in FIGS. 12, the rod coupling component 274 of the end effector 260/262 is positioned within the lumen 332 of the drive component 330 and thereby coupled to the rotatable drive component 330. As a result of this coupling, when the rotatable drive component 330 is rotated, the rod coupling component 274 is caused to rotate, thereby rotating the central rod 272 of the end effector 260/262. The central rod 272 is disposed within housing 273 and has a slot 294 defined around the outer circumference of the rod 272 that is configured to receive the pin 292, which is best shown in FIGS. 12, 14, and 16. The pin 292 is positioned through the pin hole 290 in the tubular body 270 as best shown in FIGS. 6 and 7. As best shown in FIG. 12, the pin 292 is positioned in the slot 294 such that the rod 272 can rotate but cannot move axially when the pin 292 is in the slot 294. Alternatively, instead of a pin, the housing 273 has a protrusion similar to the pin 292 that extends from an inner lumen of the housing 273 such that the protrusion can be positioned in the slot 294 in a fashion similar to the pin 292, thereby allowing the rod 272 to rotate but not move axially. The central rod 272 has an externally threaded section 390 on its distal end which threadably couples with a linear drive component 392 such that rotation of the central rod 272 causes the linear drive component 392 to move linearly. The linear drive component 392 is operably coupled to the grasper 266 or pair of scissors 268 such that linear movement of the drive component 392 causes the grasper 266 or pair of scissors 268 to move between open and closed configurations. Thus, the rotation of the central rod 272 causes the grasper 266 or pair of scissors 268 to move between open and closed positions.

Returning to FIG. 8, in accordance with one implementation, the forearm 264 also has a motor 350 coupled to a drive gear 352. The drive gear 352 is coupled to the rotational gear 310 on the rotatable cylinder 302 (as best shown in FIG. 9A) such that rotation of the drive gear 352 causes the rotatable cylinder 302 to rotate. The rotatable cylinder 302 is coupled to the end effector 260/262 when the end effector 260/262 is fully seated in the lumen 300 of the forearm 264 such that rotation of the rotatable cylinder 302 causes the end effector 260/262 to rotate. That is, the protrusions 280 are positioned in the channels 304 in the lumen 300 such that the tubular body 270 is coupled to the cylinder 302 such that the tubular body 270 rotates when the cylinder 302 rotates.

In one embodiment as best shown in FIGS. 8, 11, and 13, the forearm 264 also has a support cylinder 360 positioned around the rotatable cylinder 302 and having a lumen 362 such that the rotatable cylinder 302 can be positioned in the lumen 362 and rotate in relation to the support cylinder 360.

As best shown in FIG. 13, the support cylinder 360 (shown in dotted lines) has two inner contact rings 364, 366 disposed on the inner wall of the support cylinder lumen 362. The two rings 364, 366 are configured to be in contact with the two contact leaflet pairs 306, 308 on the rotatable cylinder 302.

As best shown in FIGS. 8 and 12, both of the end effectors 260, 262 are configured to be easily coupled to and uncoupled from the forearm 264 such that a user (such as a surgeon) can easily remove and replace one end effector with another during a medical procedure. To insert either end effector 260/262 into the forearm 264 and couple it thereto as shown in FIG. 12, the end effector 260/262 is inserted into the lumen 300 such that the torque transfer protrusions 280 are positioned in the channels 304 in the lumen 300. As the end effector 260/262 is urged proximally into the lumen 300, the rod coupling component 274 will advance proximally until it is positioned in the lumen 332 of the rotatable drive component 330 and mates with the teeth 334 therein. At the same time, the proximal advancement of the end effector 260/262 causes the male protrusions 288 on the end effector coupling component 278 to advance proximally into the female channels 380 defined in the distal end of the forearm 264, as best shown in FIG. 8. The female channels 380 are configured such that once the protrusions 288 have been advanced proximally into the channels 380, the end effector 260/262 can be rotated via the handle 276 by a user to cause the protrusions 288 to rotate in the channels 288, thereby securing the end effector 260/262 to the forearm 264. Thus, a user can couple the end effector 260/262 to the forearm 264 with a single twist or rotation of the end effector 260/262. Further, the user can also remove the end effector 260/262 in the same fashion by simply twisting or rotating the handle 276 in the opposite direction.

In one implementation, any lumen in any forearm device described or contemplated herein is configured to be easy to sterilize. That is, each lumen is configured to have no crevices or other features that are inaccessible or difficult to access during sterilization. Further, certain embodiments have lumens that have dimensions that make for easy sterilization. That is, such lumens have a length that is sufficiently short and a diameter that is sufficiently large to be accessible by appropriate sterilization tools and techniques. In one specific example, any one or more of the lumens disclosed or contemplated herein can have an inside diameter of at least 3 mm and a length of 400 mm or shorter. Alternatively, the lumen(s) can have an inside diameter of at least 2 mm and a length of 250 mm or shorter. In a further alternative, the lumen(s) can have an inside diameter of at least 1 mm and a length of 125 mm or shorter. In yet another alternative, the lumen(s) can have any dimensions that simplify sterilization.

According to certain embodiments, the various forearm and end effector embodiments disclosed or contemplated herein provide for easy, quick coupling and uncoupling of the end effector to the forearm while providing for one or even two mechanical couplings or interfaces and one or two electrical couplings or interfaces. That is, the various embodiments disclosed herein allow for simple attachment of an end effector to a forearm while also providing up to two electrical couplings and up to two mechanical couplings between the forearm and the end effector.

Although the various embodiments have been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

21

What is claimed is:

1. An arm component for a medical device, the arm component comprising:

- (a) an arm body;
- (b) a rotatable cylinder disposed within the arm body, the rotatable cylinder comprising:
 - (i) a fluidically sealed end effector lumen defined within the rotatable cylinder; and
 - (ii) at least one torque transfer channel defined in a wall of the end effector lumen; and
- (c) a rotatable drive component operably coupled to the rotatable cylinder, the rotatable drive component comprising:
 - (i) a rotatable body; and
 - (ii) a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises mating features defined within the drive component lumen.

2. The arm component of claim 1, further comprising a ring seal disposed between the arm body and the rotatable cylinder.

3. The arm component of claim 1, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.

4. The arm component of claim 1, further comprising a second motor operably coupled to a second drive gear, wherein the second drive gear is operably coupled to a driven gear operably coupled to the rotatable drive component, wherein actuation of the second motor causes rotation of the rotatable drive component.

5. The arm component of claim 1, further comprising:

- (a) a first outer contact ring disposed around the rotatable cylinder;
- (b) a second outer contact ring disposed around the rotatable cylinder;
- (c) a first contact component disposed on an outer wall of the rotatable cylinder such that the first contact component is in continuous contact with the first inner contact ring regardless of a rotational position of the rotatable cylinder;
- (d) a second contact component disposed on the outer wall of the rotatable cylinder such that the second contact component is in continuous contact with the second inner contact ring regardless of the rotational position of the rotatable cylinder;
- (e) a first inner contact ring disposed on the inner wall of the end effector lumen; and
- (f) a second inner contact ring disposed on the inner wall of the end effector lumen.

6. The arm component of claim 5, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising first and second end effector contact components, wherein the first end effector contact component is in contact with the first inner contact ring and the second end effector contact component is in contact with the second inner contact ring when the quick-release end effector is operably coupled to the arm.

7. The arm component of claim 1, further comprising a quick-release end effector configured to be positionable within the end effector lumen, the quick-release end effector comprising:

22

(a) an end effector body;

(b) at least one second torque transfer protrusion defined on an exterior portion of the end effector body, wherein the at least one second torque transfer protrusion is configured to be coupleable with the at least one first torque transfer channel in the end effector lumen;

(c) a rod disposed within the end effector body; and

(d) a rod coupling component disposed at a proximal portion of the rod, wherein the rod coupling component is configured to be coupleable with the mating features associated with the lumen of the rotatable drive component.

8. The arm component of claim 1, wherein the at least one torque transfer channel extends longitudinally along the wall from a distal end of the end effector lumen.

9. The arm component of claim 1, wherein the rotatable drive component is configured to effect linear movement of an end effector attached to the arm component.

10. An end effector for a medical device, the end effector comprising:

(a) an end effector body;

(b) an end effector coupling component disposed around the end effector body, the end effector coupling component comprising at least one male protrusion extending from the coupling component;

(c) at least one first torque transfer protrusion defined in an exterior portion of the end effector body;

(d) a rod disposed within the end effector body; and

(e) a rod coupling component disposed at a proximal portion of the rod, the rod coupling component comprising at least one first coupling protrusions associated with an external portion of the rod coupling component.

11. The end effector of claim 10, further comprising an end effector disposed at a distal end of the end effector body, wherein the end effector is operably coupled to the rod such that actuation of the rod causes actuation of the end effector.

12. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device.

13. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device, the lumen comprising at least one second torque transfer channel defined in the lumen, wherein the at least one second torque transfer channel is configured to be coupleable with the at least one first torque transfer protrusion in the exterior portion of the end effector body.

14. The end effector of claim 10, wherein the end effector body is configured to be positionable in a lumen of an arm of a medical device, wherein the arm comprises at least one female channel defined in a distal portion of the arm, wherein the end effector coupling component is configured to be coupleable to the arm such that the at least one male protrusion is mateable with the at least one female channel.

15. The end effector of claim 10, wherein the end effector is configured to be positionable in an arm of a medical device, wherein the arm comprises:

(a) an arm body;

(b) a rotatable cylinder disposed within the arm body, the rotatable cylinder comprising:

(i) an end effector lumen defined within the rotatable cylinder; and

(ii) at least one second torque transfer channel defined in a wall of the end effector lumen; and

23

- (c) a rotatable drive component operably coupled to the rotatable cylinder, the drive component comprising:
- (i) a rotatable body; and
 - (ii) a lumen defined in a distal portion of the rotatable body, wherein the lumen comprises at least one second coupling protrusion disposed within the lumen,

wherein the at least one first coupling protrusion of the rod coupling component is configured to be coupleable with the at least one second coupling protrusion disposed within the lumen of the rotatable drive component.

16. The end effector of claim 10, further comprising first and second contact rings disposed around the rod.

17. The end effector of claim 16, further comprising a grasper end effector comprising first and second grasper arms, wherein the first contact ring is electrically coupled to the first grasper arm and the second contact ring is electrically coupled to the second grasper arm.

18. An arm component for a medical device, the arm component comprising:

- (a) an arm;
- (b) a rotatable drive component rotatably disposed within the arm and operably coupled to a motor, the rotatable drive component comprising:

24

- (i) a rotatable body; and
 - (ii) a drive component lumen defined in a distal portion of the rotatable body, wherein the drive component lumen comprises at least one protrusion;
- (c) a rotatable cylinder disposed within the arm body distal from and operably coupled to the rotatable drive component, the rotatable cylinder comprising:
- (i) a fluidically sealed end effector lumen defined within the rotatable cylinder; and
 - (ii) at least one of a torque transfer channel and a torque transfer protrusion defined in a wall of the end effector lumen.

19. The arm component of claim 18, wherein the at least one of a torque transfer protrusion and a torque transfer channel is configured to mate with the other of a torque transfer protrusion and a torque transfer channel disposed on an end effector.

20. The arm component of claim 18, further comprising a first motor operably coupled to a first drive gear, wherein the first drive gear is operably coupled to an external gear disposed on an outer wall of the rotatable cylinder, wherein actuation of the first motor causes rotation of the rotatable cylinder.

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