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(54) **SELECTIVE DRUG DELIVERY IN A LUMEN**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

164,184 A 6/1875 Jeome
1,167,014 A 1/1916 O'Brien

(Continued)

FOREIGN PATENT DOCUMENTS

CA 2384866 A1 5/2001
CN 101583323 A 11/2009

(Continued)

OTHER PUBLICATIONS

Van Den Berg, "Light echoes image the human body," OLE, Oct. 2001, p. 35-37.

(Continued)

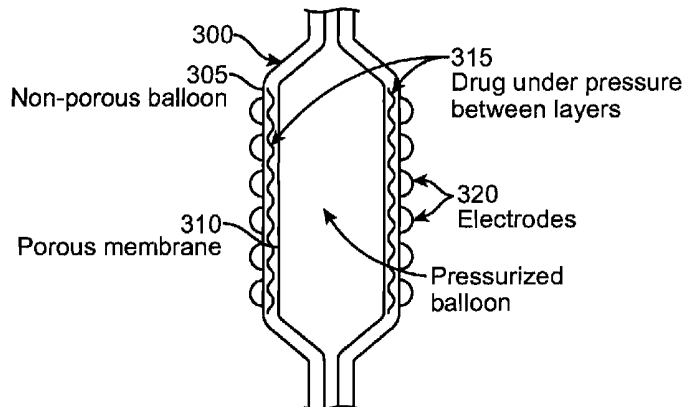
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(57) **ABSTRACT**

Methods and systems are disclosed for selective drug or fluid delivery in a lumen through a coating or fluid delivery channels. One system includes an elongate catheter having a proximal end and a distal end with an axis therebetween, the catheter having a radially expandable balloon near the distal end and an energy delivery portion proximate the balloon for transmission of energy, a thermally changeable coating having a releasable drug coupled to the balloon, the thermally changeable coating being oriented to be urged against the body tissue when the expandable balloon expands and an energy source operatively coupled to the energy delivery portion configured to energize the energy delivery portion to heat and liquefy the thermally changeable coating to release the drug to the body tissue.

19 Claims, 4 Drawing Sheets



(51)	Int. Cl.		5,143,836 A	9/1992	Hartman et al.
	<i>A61B 5/00</i>	(2006.01)	5,156,610 A	10/1992	Reger et al.
	<i>A61B 18/14</i>	(2006.01)	5,158,564 A	10/1992	Schnepp-Pesch
	<i>A61L 29/08</i>	(2006.01)	5,170,802 A	12/1992	Mehra
	<i>A61L 29/14</i>	(2006.01)	5,178,620 A	1/1993	Eggers et al.
	<i>A61L 29/16</i>	(2006.01)	5,178,625 A	1/1993	Groshong et al.
	<i>A61B 18/24</i>	(2006.01)	5,190,540 A	3/1993	Lee
	<i>A61B 18/00</i>	(2006.01)	5,211,651 A	5/1993	Reger et al.
	<i>A61B 18/18</i>	(2006.01)	5,234,407 A	8/1993	Teirstein et al.
	<i>A61M 37/00</i>	(2006.01)	5,242,441 A	9/1993	Avitall
	<i>A61N 7/02</i>	(2006.01)	5,251,634 A	10/1993	Weinberg et al.
(52)	U.S. Cl.		5,255,679 A	10/1993	Imran
	CPC		5,263,493 A	11/1993	Avitall
	<i>A61B 18/1492</i> (2013.01); <i>A61L 29/08</i>		5,267,954 A	12/1993	Nita et al.
	(2013.01); <i>A61L 29/14</i> (2013.01); <i>A61L 29/16</i>		5,277,201 A	1/1994	Stern et al.
	(2013.01); <i>A61M 25/104</i> (2013.01); <i>A61B</i>		5,282,484 A	2/1994	Reger et al.
	<i>18/24</i> (2013.01); <i>A61B 2018/0022</i> (2013.01);		5,286,254 A	2/1994	Shaplant et al.
	<i>A61B 2018/00154</i> (2013.01); <i>A61B 2018/00214</i>		5,295,484 A	3/1994	Marcus
	(2013.01); <i>A61B 2018/00898</i> (2013.01); <i>A61B</i>		5,297,564 A	3/1994	Love et al.
	<i>2018/1861</i> (2013.01); <i>A61L 2300/45</i> (2013.01);		5,300,068 A	4/1994	Rosar et al.
	<i>A61L 2300/606</i> (2013.01); <i>A61M 37/0092</i>		5,301,683 A	4/1994	Durkan
	(2013.01); <i>A61M 2025/105</i> (2013.01); <i>A61M</i>		5,304,115 A	4/1994	Pflueger et al.
	<i>2025/1086</i> (2013.01); <i>A61M 2025/1088</i>		5,304,121 A	4/1994	Sahatjian
	(2013.01); <i>A61N 7/022</i> (2013.01)		5,304,171 A	4/1994	Gregory et al.
			5,304,173 A	4/1994	Kittrell et al.
			5,306,250 A	4/1994	March et al.
			5,312,328 A	5/1994	Nita et al.
			5,314,466 A	5/1994	Stern et al.
			5,322,064 A	6/1994	Lundquist
			5,324,255 A	6/1994	Passafaro et al.
			5,326,341 A	7/1994	Lew et al.
			5,326,342 A	7/1994	Pflueger et al.
			5,330,518 A	7/1994	Neilson et al.
			5,333,614 A	8/1994	Feiring
			5,342,292 A	8/1994	Nita et al.
			5,344,395 A	9/1994	Whalen et al.
			5,364,392 A	11/1994	Warner et al.
			5,365,172 A	11/1994	Hrovat et al.
			5,368,557 A	11/1994	Nita et al.
			5,368,558 A	11/1994	Nita et al.
			5,380,274 A	1/1995	Nita et al.
			5,380,319 A	1/1995	Saito et al.
			5,382,228 A	1/1995	Nita et al.
			5,383,874 A	1/1995	Jackson et al.
			5,383,917 A	1/1995	Desai et al.
			5,397,301 A	3/1995	Pflueger et al.
			5,397,339 A	3/1995	Desai
			5,401,272 A	3/1995	Perkins et al.
			5,403,311 A	4/1995	Abele et al.
			5,405,318 A	4/1995	Nita et al.
			5,405,346 A	4/1995	Grundy et al.
			5,409,000 A	4/1995	Imran
			5,417,672 A	5/1995	Nita et al.
			5,419,767 A	5/1995	Eggers et al.
			5,427,118 A	6/1995	Nita et al.
			5,432,876 A	7/1995	Appeldorn et al.
			5,441,498 A	8/1995	Perkins et al.
			5,447,509 A	9/1995	Mills et al.
			5,451,207 A	9/1995	Yock
			5,453,091 A	9/1995	Taylor et al.
			5,454,788 A	10/1995	Walker et al.
			5,454,809 A	10/1995	Janssen
			5,455,029 A	10/1995	Hartman et al.
			5,456,682 A	10/1995	Edwards et al.
			5,457,042 A	10/1995	Hartman et al.
			5,471,982 A	12/1995	Edwards et al.
			5,474,530 A	12/1995	Passafaro et al.
			5,478,351 A	12/1995	Meade et al.
			5,496,311 A	3/1996	Abele et al.
			5,496,312 A	3/1996	Klicek et al.
			5,498,261 A	3/1996	Strul
			5,505,201 A	4/1996	Grill et al.
			5,505,730 A	4/1996	Edwards
			5,507,744 A	4/1996	Tay et al.
			5,522,873 A	6/1996	Jackman et al.
			5,531,520 A	7/1996	Grimson et al.
			5,540,656 A	7/1996	Pflueger et al.
			5,540,679 A	7/1996	Fram et al.
			5,540,681 A	7/1996	Strul et al.
(56)	References Cited				
	U.S. PATENT DOCUMENTS				
	2,505,358 A	4/1950	Gusberg et al.		
	2,701,559 A	2/1955	Cooper		
	3,108,593 A	10/1963	Glassman		
	3,108,594 A	10/1963	Glassman		
	3,540,431 A	11/1970	Mobin		
	3,952,747 A	4/1976	Kimmell		
	3,996,938 A	12/1976	Clark, III		
	4,046,150 A	9/1977	Schwartz et al.		
	4,290,427 A	9/1981	Chin		
	4,402,686 A	9/1983	Medel		
	4,483,341 A	11/1984	Witteles et al.		
	4,574,804 A	3/1986	Kurwa		
	4,587,975 A	5/1986	Salo et al.		
	4,649,936 A	3/1987	Ungar et al.		
	4,682,596 A	7/1987	Bales et al.		
	4,709,698 A	12/1987	Johnston et al.		
	4,765,331 A	8/1988	Petruzzi et al.		
	4,770,653 A	9/1988	Shturman		
	4,784,132 A	11/1988	Fox et al.		
	4,784,162 A	11/1988	Ricks et al.		
	4,785,806 A	11/1988	Deckelbaum et al.		
	4,788,975 A	12/1988	Shturman et al.		
	4,790,310 A	12/1988	Ginsburg et al.		
	4,799,479 A	1/1989	Spears		
	4,823,791 A	4/1989	D'Amelio et al.		
	4,830,003 A	5/1989	Wolff et al.		
	4,849,484 A	7/1989	Heard		
	4,862,886 A	9/1989	Clarke et al.		
	4,887,605 A	12/1989	Angelsen et al.		
	4,920,979 A	5/1990	Bullara		
	4,938,766 A	7/1990	Jarvik		
	4,955,377 A	9/1990	Lennox et al.		
	4,976,711 A	12/1990	Parins et al.		
	5,034,010 A	7/1991	Kittrell et al.		
	5,052,402 A	10/1991	Bencini et al.		
	5,053,033 A	10/1991	Clarke et al.		
	5,071,424 A	12/1991	Reger et al.		
	5,074,871 A	12/1991	Groshong et al.		
	5,098,429 A	3/1992	Sterzer et al.		
	5,098,431 A	3/1992	Rydell		
	5,102,402 A	4/1992	Dror et al.		
	RE33,925 E	5/1992	Bales et al.		
	5,109,859 A	5/1992	Jenkins		
	5,125,928 A	6/1992	Parins et al.		
	5,129,396 A	7/1992	Rosen et al.		
	5,139,496 A	8/1992	Hed		

(56)

References Cited

U.S. PATENT DOCUMENTS

5,542,917 A	8/1996	Nita et al.	5,827,203 A	10/1998	Nita et al.
5,545,161 A	8/1996	Imran	5,827,268 A	10/1998	Laufer
5,562,100 A	10/1996	Kittrell et al.	5,829,447 A	11/1998	Stevens et al.
5,571,122 A	11/1996	Kelly et al.	5,830,213 A	11/1998	Panescu et al.
5,571,151 A	11/1996	Gregory	5,830,222 A	11/1998	Makower
5,573,531 A	11/1996	Gregory et al.	5,832,228 A	11/1998	Holden et al.
5,573,533 A	11/1996	Strul	5,833,593 A	11/1998	Liprie
5,584,831 A	12/1996	McKay	5,836,874 A	11/1998	Swanson et al.
5,584,872 A	12/1996	Lafontaine et al.	5,840,076 A	11/1998	Swanson et al.
5,588,962 A *	12/1996	Nicholas et al. 604/507	5,843,016 A	12/1998	Lugnani et al.
5,599,346 A	2/1997	Edwards et al.	5,846,238 A	12/1998	Jackson et al.
5,601,526 A	2/1997	Chapelon et al.	5,846,239 A	12/1998	Swanson et al.
5,609,606 A	3/1997	O'Boyle et al.	5,846,245 A	12/1998	McCarthy et al.
5,626,576 A	5/1997	Janssen	5,848,969 A	12/1998	Panescu et al.
5,630,837 A	5/1997	Crowley	5,853,411 A	12/1998	Whayne et al.
5,637,090 A	6/1997	McGee et al.	5,855,614 A	1/1999	Stevens et al.
5,643,255 A	7/1997	Organ	5,860,974 A	1/1999	Abele
5,643,297 A	7/1997	Nordgren et al.	5,865,801 A	2/1999	Houser
5,647,847 A	7/1997	Lafontaine et al.	5,868,735 A	2/1999	Lafontaine et al.
5,649,923 A	7/1997	Gregory et al.	5,868,736 A	2/1999	Swanson et al.
5,651,780 A	7/1997	Jackson et al.	5,869,127 A	2/1999	Zhong
5,653,684 A	8/1997	Laptewicz et al.	5,871,483 A	2/1999	Jackson et al.
5,662,671 A	9/1997	Barbut et al.	5,871,524 A	2/1999	Knowlton et al.
5,665,062 A	9/1997	Houser	5,875,782 A	3/1999	Ferrari et al.
5,665,098 A	9/1997	Kelly et al.	5,876,369 A	3/1999	Houser
5,666,964 A	9/1997	Meilus	5,876,374 A	3/1999	Alba et al.
5,667,490 A	9/1997	Keith et al.	5,876,397 A	3/1999	Edelman et al.
5,672,174 A	9/1997	Gough et al.	5,879,348 A	3/1999	Owens et al.
5,676,693 A	10/1997	Lafontaine	5,891,114 A	4/1999	Chien et al.
5,678,296 A	10/1997	Fleischhacker et al.	5,891,135 A	4/1999	Jackson et al.
5,681,282 A	10/1997	Eggers et al.	5,891,136 A	4/1999	McGee et al.
RE35,656 E	11/1997	Feinberg	5,891,138 A	4/1999	Tu et al.
5,688,266 A	11/1997	Edwards et al.	5,895,378 A	4/1999	Nita
5,693,015 A	12/1997	Walker et al.	5,897,552 A	4/1999	Edwards et al.
5,693,029 A	12/1997	Leonhardt et al.	5,902,328 A	5/1999	Lafontaine et al.
5,693,043 A	12/1997	Kittrell et al.	5,904,651 A	5/1999	Swanson et al.
5,693,082 A	12/1997	Warner et al.	5,904,667 A	5/1999	Falwell et al.
5,695,504 A	12/1997	Gifford et al.	5,904,697 A	5/1999	Gifford et al.
5,697,369 A	12/1997	Long, Jr. et al.	5,904,709 A	5/1999	Arndt et al.
5,697,909 A	12/1997	Eggers et al.	5,906,614 A	5/1999	Stern et al.
5,702,386 A	12/1997	Stern et al.	5,906,623 A	5/1999	Peterson
5,702,433 A	12/1997	Taylor et al.	5,906,636 A	5/1999	Casscells et al.
5,706,809 A	1/1998	Littmann et al.	5,916,192 A	6/1999	Nita et al.
5,713,942 A	2/1998	Stern et al.	5,916,227 A	6/1999	Keith et al.
5,715,819 A	2/1998	Svenson et al.	5,916,239 A	6/1999	Geddes et al.
5,735,846 A	4/1998	Panescu et al.	5,919,219 A	7/1999	Knowlton et al.
5,741,214 A	4/1998	Ouchi et al.	5,924,424 A	7/1999	Stevens et al.
5,741,248 A	4/1998	Stern et al.	5,925,038 A	7/1999	Panescu et al.
5,741,249 A	4/1998	Moss et al.	5,934,284 A	8/1999	Plaia et al.
5,743,903 A	4/1998	Stern et al.	5,935,063 A	8/1999	Nguyen
5,748,347 A	5/1998	Erickson	5,938,670 A	8/1999	Keith et al.
5,749,914 A	5/1998	Janssen	5,947,977 A	9/1999	Slepian et al.
5,755,682 A	5/1998	Knudson et al.	5,948,011 A	9/1999	Knowlton et al.
5,755,715 A	5/1998	Stern et al.	5,951,494 A	9/1999	Wang et al.
5,755,753 A	5/1998	Knowlton et al.	5,951,539 A	9/1999	Nita et al.
5,769,847 A	6/1998	Panescu et al.	5,954,717 A	9/1999	Behl et al.
5,769,880 A	6/1998	Truckai et al.	5,957,882 A	9/1999	Nita et al.
5,775,338 A	7/1998	Hastings	5,957,941 A	9/1999	Ream et al.
5,776,174 A	7/1998	Van Tassel	5,957,969 A	9/1999	Warner et al.
5,779,698 A	7/1998	Clayman et al.	5,961,513 A	10/1999	Swanson et al.
5,782,760 A	7/1998	Schaer	5,964,757 A	10/1999	Ponzi et al.
5,785,702 A	7/1998	Murphy et al.	5,967,976 A	10/1999	Larsen et al.
5,792,105 A	8/1998	Lin et al.	5,967,978 A	10/1999	Littmann et al.
5,797,849 A	8/1998	Vesely et al.	5,967,984 A	10/1999	Chu et al.
5,797,903 A	8/1998	Swanson et al.	5,971,975 A	10/1999	Mills et al.
5,800,484 A	9/1998	Gough et al.	5,972,026 A	10/1999	Laufer et al.
5,800,494 A	9/1998	Campbell et al.	5,980,563 A	11/1999	Tu et al.
5,807,306 A	9/1998	Shapland et al.	5,989,208 A	11/1999	Nita et al.
5,810,802 A	9/1998	Panescu et al.	5,989,284 A	11/1999	Laufer
5,810,803 A	9/1998	Moss et al.	5,993,462 A	11/1999	Pomeranz et al.
5,810,810 A	9/1998	Tay et al.	5,997,497 A	12/1999	Nita et al.
5,817,092 A	10/1998	Behl	5,999,678 A	12/1999	Murphy et al.
5,817,113 A	10/1998	Gifford et al.	6,004,269 A	12/1999	Crowley et al.
5,817,144 A	10/1998	Gregory et al.	6,004,316 A	12/1999	Laufer et al.
5,823,956 A	10/1998	Roth et al.	6,007,514 A	12/1999	Nita
			6,010,522 A	1/2000	Barbut et al.
			6,013,033 A	1/2000	Berger et al.
			6,014,590 A	1/2000	Whayne et al.
			6,022,309 A	2/2000	Celliers et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,024,740	A	2/2000	Lesh et al.	6,219,577	B1	4/2001	Brown, III et al.
6,030,611	A	2/2000	Gorecki et al.	6,228,076	B1	5/2001	Winston et al.
6,032,675	A	3/2000	Rubinsky et al.	6,228,109	B1	5/2001	Tu et al.
6,033,397	A	3/2000	Laufer et al.	6,231,516	B1	5/2001	Keilman et al.
6,033,398	A	3/2000	Farley et al.	6,231,587	B1	5/2001	Makower
6,036,687	A	3/2000	Laufer et al.	6,235,044	B1	5/2001	Root et al.
6,036,689	A	3/2000	Tu et al.	6,236,883	B1	5/2001	Ciaccio et al.
6,041,260	A	3/2000	Stern et al.	6,237,605	B1	5/2001	Vaska et al.
6,050,994	A	4/2000	Sherman et al.	6,238,389	B1	5/2001	Paddock et al.
6,056,744	A	5/2000	Edwards	6,238,392	B1	5/2001	Long
6,056,746	A	5/2000	Goble et al.	6,241,666	B1	6/2001	Pomeranz et al.
6,063,085	A	5/2000	Tay et al.	6,241,753	B1	6/2001	Knowlton
6,066,096	A	5/2000	Smith et al.	6,245,020	B1	6/2001	Moore et al.
6,066,139	A	5/2000	Ryan et al.	6,245,045	B1	6/2001	Stratienko
6,068,638	A	5/2000	Makower	6,248,126	B1	6/2001	Lesser et al.
6,068,653	A	5/2000	Lafontaine	6,251,128	B1	6/2001	Knopp et al.
6,071,277	A	6/2000	Farley et al.	6,258,087	B1	7/2001	Edwards et al.
6,071,278	A	6/2000	Panescu et al.	6,273,886	B1	8/2001	Edwards et al.
6,078,839	A	6/2000	Carson	6,280,466	B1	8/2001	Kugler et al.
6,079,414	A	6/2000	Roth	6,283,935	B1	9/2001	Laufer et al.
6,080,171	A	6/2000	Keith et al.	6,283,959	B1	9/2001	Lalonde et al.
6,081,749	A	6/2000	Ingle et al.	6,284,743	B1	9/2001	Parmacek et al.
6,083,159	A	7/2000	Driscoll et al.	6,287,323	B1	9/2001	Hammerslag
6,086,581	A	7/2000	Reynolds et al.	6,290,696	B1	9/2001	Lafontaine
6,091,995	A	7/2000	Ingle et al.	6,292,695	B1	9/2001	Webster, Jr. et al.
6,093,166	A	7/2000	Knudson et al.	6,293,942	B1	9/2001	Goble et al.
6,096,021	A	8/2000	Helm et al.	6,293,943	B1	9/2001	Panescu et al.
6,099,526	A	8/2000	Wayne et al.	6,296,619	B1	10/2001	Brisken et al.
6,102,908	A	8/2000	Tu et al.	6,298,256	B1	10/2001	Meyer
6,106,477	A	8/2000	Miesel et al.	6,299,379	B1	10/2001	Lewis
6,110,187	A	8/2000	Donlon et al.	6,299,623	B1	10/2001	Wulfman
6,114,311	A	9/2000	Parmacek et al.	6,309,379	B1	10/2001	Willard et al.
6,117,101	A	9/2000	Diederich et al.	6,309,399	B1	10/2001	Barbut et al.
6,117,128	A	9/2000	Gregory	6,311,090	B1	10/2001	Knowlton
6,120,476	A	9/2000	Fung et al.	6,317,615	B1	11/2001	KenKnight et al.
6,120,516	A	9/2000	Selmon et al.	6,319,242	B1	11/2001	Patterson et al.
6,121,775	A	9/2000	Pearlman	6,319,251	B1	11/2001	Tu et al.
6,123,679	A	9/2000	Lafaut et al.	6,322,559	B1	11/2001	Daulton et al.
6,123,682	A	9/2000	Knudson et al.	6,325,797	B1	12/2001	Stewart et al.
6,123,702	A	9/2000	Swanson et al.	6,325,799	B1	12/2001	Goble
6,123,703	A	9/2000	Tu et al.	6,328,699	B1	12/2001	Eigler et al.
6,123,718	A	9/2000	Tu et al.	6,346,074	B1	2/2002	Roth
6,129,725	A	10/2000	Tu et al.	6,346,104	B2	2/2002	Daly et al.
6,135,997	A	10/2000	Laufer et al.	6,350,248	B1	2/2002	Knudson et al.
6,142,991	A	11/2000	Schatzberger et al.	6,350,276	B1	2/2002	Knowlton
6,142,993	A	11/2000	Wayne et al.	6,353,751	B1	3/2002	Swanson et al.
6,149,647	A	11/2000	Tu et al.	6,355,029	B1	3/2002	Joye et al.
6,152,899	A	11/2000	Farley et al.	6,357,447	B1	3/2002	Swanson et al.
6,152,912	A	11/2000	Jansen et al.	6,361,519	B1	3/2002	Knudson et al.
6,156,046	A	12/2000	Passafaro et al.	6,364,840	B1	4/2002	Crowley
6,158,250	A	12/2000	Tibbals et al.	6,371,965	B2	4/2002	Gifford, III et al.
6,159,187	A	12/2000	Park et al.	6,375,668	B1	4/2002	Gifford et al.
6,159,225	A	12/2000	Makower	6,377,854	B1	4/2002	Knowlton
6,161,048	A	12/2000	Sluijter et al.	6,377,855	B1	4/2002	Knowlton
6,162,184	A	12/2000	Swanson et al.	6,379,352	B1	4/2002	Reynolds et al.
6,165,163	A	12/2000	Chien et al.	6,379,373	B1	4/2002	Sawhney et al.
6,165,172	A	12/2000	Farley et al.	6,381,497	B1	4/2002	Knowlton
6,165,187	A	12/2000	Reger et al.	6,381,498	B1	4/2002	Knowlton
6,168,594	B1	1/2001	Lafontaine et al.	6,383,151	B1	5/2002	Diederich et al.
6,171,321	B1	1/2001	Gifford, III et al.	6,387,105	B1	5/2002	Gifford, III et al.
6,179,832	B1	1/2001	Jones et al.	6,387,380	B1	5/2002	Knowlton
6,179,835	B1	1/2001	Panescu et al.	6,389,311	B1	5/2002	Wayne et al.
6,179,859	B1	1/2001	Bates et al.	6,389,314	B2	5/2002	Feiring
6,183,468	B1	2/2001	Swanson et al.	6,391,024	B1	5/2002	Sun et al.
6,183,486	B1	2/2001	Snow et al.	6,394,096	B1	5/2002	Constantz
6,190,379	B1	2/2001	Heuser et al.	6,394,956	B1	5/2002	Chandrasekaran et al.
6,191,862	B1	2/2001	Swanson et al.	6,398,780	B1	6/2002	Farley et al.
6,197,021	B1	3/2001	Panescu et al.	6,398,782	B1	6/2002	Pecor et al.
6,200,266	B1	3/2001	Shokrollahi et al.	6,398,792	B1	6/2002	O'Connor
6,203,537	B1	3/2001	Adrian	6,401,720	B1	6/2002	Stevens et al.
6,203,561	B1	3/2001	Ramee et al.	6,402,719	B1	6/2002	Ponzi et al.
6,210,406	B1	4/2001	Webster	6,405,090	B1	6/2002	Knowlton
6,211,247	B1	4/2001	Goodman	6,409,723	B1	6/2002	Edwards
6,216,704	B1	4/2001	Ingle et al.	6,413,255	B1	7/2002	Stern
6,217,576	B1	4/2001	Tu et al.	6,421,559	B1	7/2002	Pearlman
				6,423,057	B1	7/2002	He et al.
				6,425,867	B1	7/2002	Vaezy et al.
				6,425,912	B1	7/2002	Knowlton
				6,427,118	B1	7/2002	Suzuki

(56)

References Cited

U.S. PATENT DOCUMENTS

6,428,534	B1	8/2002	Joye et al.	6,577,902	B1	6/2003	Laufer et al.
6,428,536	B2	8/2002	Panescu et al.	6,579,308	B1	6/2003	Jansen et al.
6,430,446	B1	8/2002	Knowlton	6,579,311	B1	6/2003	Makower
6,432,102	B2	8/2002	Joye et al.	6,582,423	B1	6/2003	Thapliyal et al.
6,436,056	B1	8/2002	Wang et al.	6,589,238	B2	7/2003	Edwards et al.
6,438,424	B1	8/2002	Knowlton	6,592,526	B1	7/2003	Lenker
6,440,125	B1	8/2002	Rentrop	6,592,567	B1	7/2003	Levin et al.
6,442,413	B1	8/2002	Silver	6,595,959	B1	7/2003	Stratienko
6,443,965	B1	9/2002	Gifford, III et al.	6,600,956	B2	7/2003	Maschino et al.
6,445,939	B1	9/2002	Swanson et al.	6,602,242	B1	8/2003	Fung et al.
6,447,505	B2	9/2002	McGovern et al.	6,602,246	B1	8/2003	Joye et al.
6,447,509	B1	9/2002	Bonnet et al.	6,605,061	B2	8/2003	Vantassel et al.
6,451,034	B1	9/2002	Gifford, III et al.	6,605,084	B2	8/2003	Acker et al.
6,451,044	B1	9/2002	Naghavi et al.	6,623,452	B2	9/2003	Chien et al.
6,453,202	B1	9/2002	Knowlton	6,623,453	B1	9/2003	Guibert et al.
6,454,737	B1	9/2002	Nita et al.	6,632,193	B1	10/2003	Davison et al.
6,454,757	B1	9/2002	Nita et al.	6,632,196	B1	10/2003	Houser
6,454,775	B1	9/2002	Demarais et al.	6,645,223	B2	11/2003	Boyle et al.
6,458,098	B1	10/2002	Kanesaka	6,648,854	B1	11/2003	Patterson et al.
6,461,378	B1	10/2002	Knowlton	6,648,878	B2	11/2003	Lafontaine
6,468,276	B1	10/2002	McKay	6,648,879	B2	11/2003	Joye et al.
6,468,297	B1	10/2002	Williams et al.	6,651,672	B2	11/2003	Roth
6,470,216	B1	10/2002	Knowlton	6,652,513	B2	11/2003	Panescu et al.
6,470,219	B1	10/2002	Edwards et al.	6,652,515	B1	11/2003	Maguire et al.
6,471,689	B1*	10/2002	Joseph et al. 604/892.1	6,656,136	B1	12/2003	Weng et al.
6,471,696	B1	10/2002	Berube et al.	6,658,279	B2	12/2003	Swanson et al.
6,475,213	B1	11/2002	Whyne et al.	6,659,981	B2	12/2003	Stewart et al.
6,475,215	B1	11/2002	Tanrisever	6,666,858	B2	12/2003	Lafontaine
6,475,238	B1	11/2002	Fedida et al.	6,666,863	B2	12/2003	Wentzel et al.
6,477,426	B1	11/2002	Fenn et al.	6,669,655	B1	12/2003	Acker et al.
6,480,745	B2	11/2002	Nelson et al.	6,669,692	B1	12/2003	Nelson et al.
6,481,704	B1	11/2002	Koster et al.	6,673,040	B1	1/2004	Samson et al.
6,482,202	B1	11/2002	Goble et al.	6,673,064	B1	1/2004	Rentrop
6,484,052	B1	11/2002	Visuri et al.	6,673,066	B2	1/2004	Werneth
6,485,489	B2	11/2002	Teirstein et al.	6,673,090	B2	1/2004	Root et al.
6,488,679	B1	12/2002	Swanson et al.	6,673,101	B1	1/2004	Fitzgerald et al.
6,489,307	B1	12/2002	Phillips et al.	6,673,290	B1	1/2004	Whyne et al.
6,491,705	B2	12/2002	Gifford, III et al.	6,676,678	B2	1/2004	Gifford, III et al.
6,494,891	B1	12/2002	Cornish et al.	6,679,268	B2	1/2004	Stevens et al.
6,497,711	B1	12/2002	Plaia et al.	6,681,773	B2	1/2004	Murphy et al.
6,500,172	B1	12/2002	Panescu et al.	6,682,541	B1	1/2004	Gifford, III et al.
6,500,174	B1	12/2002	Maguire et al.	6,684,098	B2	1/2004	Oshio et al.
6,508,765	B2	1/2003	Suorsa et al.	6,685,732	B2	2/2004	Kramer
6,508,804	B2	1/2003	Sarge et al.	6,685,733	B1	2/2004	Dae et al.
6,508,815	B1	1/2003	Strul et al.	6,689,086	B1	2/2004	Nita et al.
6,511,478	B1	1/2003	Burnside et al.	6,689,148	B2	2/2004	Sawhney et al.
6,511,496	B1	1/2003	Huter et al.	6,690,181	B1	2/2004	Dowdeswell et al.
6,511,500	B1	1/2003	Rahme	6,692,490	B1	2/2004	Edwards
6,514,236	B1	2/2003	Stratienko	6,695,830	B2	2/2004	Vigil et al.
6,514,245	B1	2/2003	Williams et al.	6,695,857	B2	2/2004	Gifford, III et al.
6,514,248	B1	2/2003	Eggers et al.	6,699,241	B2	3/2004	Rappaport et al.
6,517,534	B1	2/2003	McGovern et al.	6,699,257	B2	3/2004	Gifford, III et al.
6,517,572	B2	2/2003	Kugler et al.	6,702,748	B1	3/2004	Nita et al.
6,522,913	B2	2/2003	Swanson et al.	6,702,811	B2	3/2004	Stewart et al.
6,522,926	B1	2/2003	Kieval et al.	6,706,010	B1	3/2004	Miki et al.
6,524,299	B1	2/2003	Tran et al.	6,706,011	B1	3/2004	Murphy-Chutorian et al.
6,527,765	B2	3/2003	Kelman et al.	6,706,037	B2	3/2004	Zvuloni et al.
6,527,769	B2	3/2003	Langberg et al.	6,709,431	B2	3/2004	Lafontaine
6,540,761	B2	4/2003	Houser	6,711,429	B1	3/2004	Gilboa et al.
6,542,781	B1	4/2003	Koblish et al.	6,712,815	B2	3/2004	Sampson et al.
6,544,780	B1	4/2003	Wang	6,714,822	B2	3/2004	King et al.
6,546,272	B1	4/2003	MacKinnon et al.	6,716,184	B2	4/2004	Vaezy et al.
6,547,788	B1	4/2003	Maguire et al.	6,720,350	B2	4/2004	Kunz et al.
6,549,800	B1	4/2003	Atalar et al.	6,723,043	B2	4/2004	Kleeman et al.
6,552,796	B2	4/2003	Magnin et al.	6,723,064	B2	4/2004	Babaev
6,554,780	B1	4/2003	Sampson et al.	6,736,811	B2	5/2004	Panescu et al.
6,558,381	B2	5/2003	Ingle et al.	6,743,184	B2	6/2004	Sampson et al.
6,558,382	B2	5/2003	Jahns et al.	6,746,401	B2	6/2004	Panescu
6,564,096	B2	5/2003	Mest	6,746,464	B1	6/2004	Makower
6,565,582	B2	5/2003	Gifford, III et al.	6,746,474	B2	6/2004	Saadat
6,569,109	B2	5/2003	Sakurai et al.	6,748,953	B2	6/2004	Sherry et al.
6,569,177	B1	5/2003	Dillard et al.	6,749,607	B2	6/2004	Edwards et al.
6,570,659	B2	5/2003	Schmitt	6,752,805	B2	6/2004	Maguire et al.
6,572,551	B1	6/2003	Smith et al.	6,760,616	B2	7/2004	Hoey et al.
6,572,612	B2	6/2003	Stewart et al.	6,763,261	B2	7/2004	Casscells, III et al.
				6,764,501	B2	7/2004	Ganz
				6,769,433	B2	8/2004	Zikorus et al.
				6,770,070	B1	8/2004	Balbierz
				6,771,996	B2	8/2004	Bowe et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,773,433	B2	8/2004	Stewart et al.	6,978,174	B2	12/2005	Gelfand et al.
6,786,900	B2	9/2004	Joye et al.	6,979,329	B2	12/2005	Burnside et al.
6,786,901	B2	9/2004	Joye et al.	6,979,420	B2	12/2005	Weber
6,786,904	B2	9/2004	Doscher et al.	6,984,238	B2	1/2006	Gifford, III et al.
6,788,977	B2	9/2004	Fenn et al.	6,985,774	B2	1/2006	Kieval et al.
6,790,206	B2	9/2004	Panescu	6,986,739	B2	1/2006	Warren et al.
6,790,222	B2	9/2004	Kugler et al.	6,989,009	B2	1/2006	Lafontaine
6,796,981	B2	9/2004	Wham et al.	6,989,010	B2	1/2006	Francischelli et al.
6,797,933	B1	9/2004	Mendis et al.	6,991,617	B2	1/2006	Hektner et al.
6,797,960	B1	9/2004	Spartiotis et al.	7,001,378	B2	2/2006	Yon et al.
6,800,075	B2	10/2004	Mische et al.	7,006,858	B2	2/2006	Silver et al.
6,802,857	B1	10/2004	Walsh et al.	7,008,667	B2	3/2006	Chudzik et al.
6,807,444	B2	10/2004	Tu et al.	7,011,508	B2	3/2006	Lum
6,811,550	B2	11/2004	Holland et al.	7,022,105	B1	4/2006	Edwards
6,813,520	B2	11/2004	Truckai et al.	7,022,120	B2	4/2006	Lafontaine
6,814,730	B2	11/2004	Li	7,025,767	B2	4/2006	Schaefer et al.
6,814,733	B2	11/2004	Schwartz et al.	7,033,322	B2	4/2006	Silver
6,823,205	B1	11/2004	Jara	7,033,372	B1	4/2006	Cahalan
6,824,516	B2	11/2004	Batten et al.	7,041,098	B2	5/2006	Farley et al.
6,827,726	B2	12/2004	Parodi	7,050,848	B2	5/2006	Hoey et al.
6,827,926	B2	12/2004	Robinson et al.	7,063,670	B2	6/2006	Sampson et al.
6,829,497	B2	12/2004	Mogul	7,063,679	B2	6/2006	Maguire et al.
6,830,568	B1	12/2004	Kesten et al.	7,063,719	B2	6/2006	Jansen et al.
6,837,886	B2	1/2005	Collins et al.	7,066,895	B2	6/2006	Podany
6,837,888	B2	1/2005	Ciarrocca et al.	7,066,900	B2	6/2006	Botto et al.
6,845,267	B2	1/2005	Harrison et al.	7,066,904	B2*	6/2006	Rosenthal et al. 604/103.08
6,847,848	B2	1/2005	Sterzer	7,072,720	B2	7/2006	Puskas
6,849,073	B2	2/2005	Hoey et al.	7,074,217	B2	7/2006	Strul et al.
6,849,075	B2	2/2005	Bertolero et al.	7,081,112	B2	7/2006	Joye et al.
6,853,425	B2	2/2005	Kim et al.	7,081,114	B2	7/2006	Rashidi
6,855,123	B2	2/2005	Nita	7,083,614	B2	8/2006	Fjield et al.
6,855,143	B2	2/2005	Davison et al.	7,084,276	B2	8/2006	Vu et al.
6,869,431	B2	3/2005	Maguire et al.	7,087,026	B2	8/2006	Callister et al.
6,872,183	B2	3/2005	Sampson et al.	7,087,051	B2	8/2006	Bourne et al.
6,884,260	B2	4/2005	Kugler et al.	7,087,052	B2	8/2006	Sampson et al.
6,889,694	B2	5/2005	Hooven	7,087,053	B2	8/2006	Vanney
6,893,436	B2	5/2005	Woodard et al.	7,089,065	B2	8/2006	Westlund et al.
6,895,077	B2	5/2005	Karellas et al.	7,090,655	B2	8/2006	Barry
6,895,265	B2	5/2005	Silver	7,097,641	B1	8/2006	Arless et al.
6,898,454	B2	5/2005	Atalar et al.	7,100,614	B2	9/2006	Stevens et al.
6,899,711	B2	5/2005	Stewart et al.	7,101,368	B2	9/2006	Lafontaine
6,899,718	B2	5/2005	Gifford, III et al.	7,104,983	B2	9/2006	Grasso, III et al.
6,905,494	B2	6/2005	Yon et al.	7,104,987	B2	9/2006	Biggs et al.
6,908,462	B2	6/2005	Joye et al.	7,108,715	B2	9/2006	Lawrence-Brown et al.
6,909,009	B2	6/2005	Koridze	7,112,196	B2	9/2006	Brosch et al.
6,911,026	B1	6/2005	Hall et al.	7,112,198	B2	9/2006	Satake
6,915,806	B2	7/2005	Pacek et al.	7,112,211	B2	9/2006	Gifford, III et al.
6,923,805	B1	8/2005	LaFontaine et al.	7,122,019	B1	10/2006	Kesten et al.
6,926,246	B2	8/2005	Ginggen	7,122,033	B2	10/2006	Wood
6,926,713	B2	8/2005	Rioux et al.	7,134,438	B2	11/2006	Makower et al.
6,926,716	B2	8/2005	Baker et al.	7,137,963	B2	11/2006	Nita et al.
6,929,009	B2	8/2005	Makower et al.	7,137,980	B2	11/2006	Buysse et al.
6,929,632	B2	8/2005	Nita et al.	7,153,315	B2	12/2006	Miller
6,929,639	B2	8/2005	Lafontaine	7,155,271	B2	12/2006	Halperin et al.
6,932,776	B2	8/2005	Carr	7,157,491	B2	1/2007	Mewshaw et al.
6,936,047	B2	8/2005	Nasab et al.	7,157,492	B2	1/2007	Mewshaw et al.
6,942,620	B2	9/2005	Nita et al.	7,158,832	B2	1/2007	Kieval et al.
6,942,657	B2	9/2005	Sinofsky et al.	7,160,296	B2	1/2007	Pearson et al.
6,942,677	B2	9/2005	Nita et al.	7,162,303	B2	1/2007	Levin et al.
6,942,692	B2	9/2005	Landau et al.	7,165,551	B2	1/2007	Edwards et al.
6,949,097	B2	9/2005	Stewart et al.	7,169,144	B2	1/2007	Hoey et al.
6,949,121	B1	9/2005	Laguna	7,172,589	B2	2/2007	Lafontaine
6,952,615	B2	10/2005	Satake	7,172,610	B2	2/2007	Heitzmann et al.
6,953,425	B2	10/2005	Brister	7,181,261	B2	2/2007	Silver et al.
6,955,174	B2	10/2005	Joye	7,184,811	B2	2/2007	Phan et al.
6,955,175	B2	10/2005	Stevens et al.	7,184,827	B1	2/2007	Edwards
6,958,075	B2	10/2005	Mon et al.	7,189,227	B2	3/2007	Lafontaine
6,959,711	B2	11/2005	Murphy et al.	7,192,427	B2	3/2007	Chapelon et al.
6,960,207	B2	11/2005	Vanney et al.	7,192,586	B2	3/2007	Bander
6,962,584	B1	11/2005	Stone	7,197,354	B2	3/2007	Sobe
6,964,660	B2	11/2005	Maguire et al.	7,198,632	B2	4/2007	Lim et al.
6,966,908	B2	11/2005	Maguire et al.	7,200,445	B1	4/2007	Dalbec et al.
6,972,015	B2	12/2005	Joye et al.	7,201,749	B2	4/2007	Govari et al.
6,972,024	B1	12/2005	Kilpatrick	7,203,537	B2	4/2007	Mower
6,974,456	B2	12/2005	Edwards et al.	7,214,234	B2	5/2007	Rapacki et al.
				7,220,233	B2	5/2007	Nita et al.
				7,220,239	B2	5/2007	Wilson et al.
				7,220,257	B1	5/2007	Lafontaine
				7,220,270	B2	5/2007	Sawhney et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,232,458 B2	6/2007	Saadat	7,481,803 B2	1/2009	Kesten et al.
7,232,459 B2	6/2007	Greenberg et al.	7,485,104 B2	2/2009	Kieval
7,238,184 B2	7/2007	Megerman et al.	7,486,805 B2	2/2009	Krattiger
7,241,273 B2	7/2007	Maguire et al.	7,487,780 B2	2/2009	Hooven
7,241,736 B2	7/2007	Hunter et al.	7,493,154 B2	2/2009	Bonner et al.
7,247,141 B2	7/2007	Makin et al.	7,494,485 B2	2/2009	Beck et al.
7,250,041 B2	7/2007	Chiu et al.	7,494,486 B2	2/2009	Mische et al.
7,250,440 B2	7/2007	Mewshaw et al.	7,494,488 B2	2/2009	Weber
7,252,664 B2	8/2007	Nasab et al.	7,494,661 B2	2/2009	Sanders
7,252,679 B2	8/2007	Fischell et al.	7,495,439 B2	2/2009	Wiggins
7,264,619 B2	9/2007	Venturelli	7,497,858 B2	3/2009	Chapelon et al.
7,279,600 B2	10/2007	Mewshaw et al.	7,499,745 B2	3/2009	Littrup et al.
7,280,863 B2	10/2007	Shachar	7,500,985 B2	3/2009	Saadat
7,282,213 B2	10/2007	Schroeder et al.	7,505,812 B1	3/2009	Eggers et al.
7,285,119 B2	10/2007	Stewart et al.	7,505,816 B2	3/2009	Schmeling et al.
7,285,120 B2	10/2007	Im et al.	7,507,233 B2	3/2009	Littrup et al.
7,288,089 B2	10/2007	Yon et al.	7,507,235 B2	3/2009	Keogh et al.
7,288,096 B2	10/2007	Chin	7,511,494 B2	3/2009	Wedeen
7,291,146 B2	11/2007	Steinke et al.	7,512,445 B2	3/2009	Truckai et al.
7,293,562 B2	11/2007	Malecki et al.	7,527,643 B2	5/2009	Case et al.
7,294,125 B2	11/2007	Phalen et al.	7,529,589 B2	5/2009	Williams et al.
7,294,126 B2	11/2007	Sampson et al.	7,540,852 B2	6/2009	Nita et al.
7,294,127 B2	11/2007	Leung et al.	7,540,870 B2	6/2009	Babaev
7,297,131 B2	11/2007	Nita	RE40,863 E	7/2009	Tay et al.
7,297,475 B2	11/2007	Koiwai et al.	7,556,624 B2	7/2009	Laufer et al.
7,300,433 B2	11/2007	Lane et al.	7,558,625 B2	7/2009	Levin et al.
7,301,108 B2	11/2007	Egitto et al.	7,563,247 B2	7/2009	Maguire et al.
7,310,150 B2	12/2007	Guillermo et al.	7,563,262 B2	7/2009	Winston et al.
7,313,430 B2	12/2007	Urquhart et al.	7,566,319 B2	7/2009	McAuley et al.
7,314,483 B2	1/2008	Landau et al.	7,569,052 B2	8/2009	Phan et al.
7,317,077 B2	1/2008	Averback et al.	7,582,111 B2	9/2009	Krolik et al.
7,323,006 B2	1/2008	Andreas et al.	7,584,004 B2	9/2009	Caparso et al.
7,326,206 B2	2/2008	Paul et al.	7,585,835 B2	9/2009	Hill et al.
7,326,226 B2	2/2008	Root et al.	7,591,996 B2	9/2009	Hwang et al.
7,326,235 B2	2/2008	Edwards	7,597,704 B2	10/2009	Frazier et al.
7,326,237 B2	2/2008	DePalma et al.	7,598,228 B2	10/2009	Hattori et al.
7,329,236 B2	2/2008	Kesten et al.	7,599,730 B2	10/2009	Hunter et al.
7,335,180 B2	2/2008	Nita et al.	7,603,166 B2	10/2009	Casscells, III et al.
7,335,192 B2	2/2008	Keren et al.	7,604,608 B2	10/2009	Nita et al.
7,338,467 B2	3/2008	Lutter	7,604,633 B2	10/2009	Truckai et al.
7,341,570 B2	3/2008	Keren et al.	7,615,015 B2	11/2009	Coleman
7,343,195 B2	3/2008	Strommer et al.	7,615,072 B2	11/2009	Rust et al.
7,347,857 B2	3/2008	Anderson et al.	7,617,005 B2	11/2009	Demarais et al.
7,348,003 B2	3/2008	Salcedo et al.	7,620,451 B2	11/2009	Demarais et al.
7,352,593 B2	4/2008	Zeng et al.	7,621,902 B2	11/2009	Nita et al.
7,354,927 B2	4/2008	Vu	7,621,929 B2	11/2009	Nita et al.
7,359,732 B2	4/2008	Kim et al.	7,626,015 B2	12/2009	Feinstein et al.
7,361,341 B2	4/2008	Salcedo et al.	7,626,235 B2	12/2009	Kinoshita
7,364,566 B2	4/2008	Elkins et al.	7,632,268 B2	12/2009	Edwards et al.
7,367,970 B2	5/2008	Govari et al.	7,632,845 B2	12/2009	Vu et al.
7,367,975 B2	5/2008	Malecki et al.	7,635,383 B2	12/2009	Gumm
7,371,231 B2	5/2008	Rioux et al.	7,640,046 B2	12/2009	Pastore et al.
7,387,126 B2	6/2008	Cox et al.	7,641,633 B2	1/2010	Laufer et al.
7,393,338 B2	7/2008	Nita	7,641,679 B2	1/2010	Joye et al.
7,396,355 B2	7/2008	Goldman et al.	7,646,544 B2	1/2010	Batchko et al.
7,402,151 B2	7/2008	Rosenman et al.	7,647,115 B2	1/2010	Levin et al.
7,402,312 B2	7/2008	Rosen et al.	7,653,438 B2	1/2010	Deem et al.
7,404,824 B1	7/2008	Webler et al.	7,655,006 B2	2/2010	Sauvageau et al.
7,406,970 B2	8/2008	Zikorus et al.	7,662,114 B2	2/2010	Seip et al.
7,407,502 B2	8/2008	Strul et al.	7,664,548 B2	2/2010	Amurthur et al.
7,407,506 B2	8/2008	Makower	7,670,279 B2	3/2010	Gertner
7,407,671 B2	8/2008	McBride et al.	7,670,335 B2	3/2010	Keidar
7,408,021 B2	8/2008	Averback et al.	7,671,084 B2	3/2010	Mewshaw et al.
7,410,486 B2	8/2008	Fuimaono et al.	7,678,104 B2	3/2010	Keidar
7,413,556 B2	8/2008	Zhang et al.	7,678,106 B2	3/2010	Lee
7,425,212 B1	9/2008	Danek et al.	7,678,108 B2	3/2010	Chrisitian et al.
7,426,409 B2	9/2008	Casscells, III et al.	7,691,080 B2	4/2010	Seward et al.
7,435,248 B2	10/2008	Taimisto et al.	7,699,809 B2	4/2010	Urmey
7,447,453 B2	11/2008	Kim et al.	7,706,882 B2	4/2010	Francischelli et al.
7,447,543 B2	11/2008	Belacazar et al.	7,715,912 B2	5/2010	Rezaei et al.
7,449,018 B2	11/2008	Kramer	7,717,853 B2	5/2010	Nita
7,452,538 B2	11/2008	Ni et al.	7,717,909 B2	5/2010	Strul et al.
7,473,890 B2	1/2009	Grier et al.	7,717,948 B2	5/2010	Demarais et al.
7,476,384 B2	1/2009	Ni et al.	7,722,539 B2	5/2010	Carter et al.
7,479,157 B2	1/2009	Weber et al.	7,725,157 B2	5/2010	Dumoulin et al.
			7,727,178 B2	6/2010	Wilson et al.
			7,736,317 B2	6/2010	Stephens et al.
			7,736,360 B2	6/2010	Mody et al.
			7,736,362 B2	6/2010	Eberl et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,738,952 B2	6/2010	Yun et al.	8,007,440 B2	8/2011	Magnin et al.
7,740,629 B2	6/2010	Anderson et al.	8,012,147 B2	9/2011	Lafontaine
7,741,299 B2	6/2010	Feinstein et al.	8,019,435 B2	9/2011	Hastings et al.
7,742,795 B2	6/2010	Stone et al.	8,021,362 B2	9/2011	Deem et al.
7,744,594 B2	6/2010	Yamazaki et al.	8,021,413 B2	9/2011	Dierking et al.
7,753,907 B2	7/2010	DiMatteo et al.	8,025,661 B2	9/2011	Arnold et al.
7,756,583 B2	7/2010	Demarais et al.	8,027,718 B2	9/2011	Spinner et al.
7,758,510 B2	7/2010	Nita et al.	8,031,927 B2	10/2011	Karl et al.
7,758,520 B2	7/2010	Griffin et al.	8,033,284 B2	10/2011	Porter et al.
7,759,315 B2	7/2010	Cuzzocrea et al.	8,048,144 B2	11/2011	Thistle et al.
7,766,833 B2	8/2010	Lee et al.	8,052,636 B2	11/2011	Moll et al.
7,766,878 B2	8/2010	Tremaglio, Jr. et al.	8,052,700 B2	11/2011	Dunn
7,766,892 B2	8/2010	Keren et al.	8,062,289 B2	11/2011	Babaev
7,767,844 B2	8/2010	Lee et al.	8,075,580 B2	12/2011	Makower
7,769,427 B2	8/2010	Shachar	8,080,006 B2	12/2011	Lafontaine et al.
7,771,372 B2	8/2010	Wilson	8,088,127 B2	1/2012	Mayse et al.
7,771,421 B2	8/2010	Stewart et al.	8,116,883 B2	2/2012	Williams et al.
7,776,967 B2	8/2010	Perry et al.	8,119,183 B2	2/2012	O'Donoghue et al.
7,777,486 B2	8/2010	Hargreaves et al.	8,120,518 B2	2/2012	Jang et al.
7,780,660 B2	8/2010	Bourne et al.	8,123,741 B2	2/2012	Marrouche et al.
7,789,876 B2	9/2010	Zikorus et al.	8,128,617 B2	3/2012	Bencini et al.
7,792,568 B2	9/2010	Zhong et al.	8,131,371 B2	3/2012	Demarais et al.
7,799,021 B2	9/2010	Leung et al.	8,131,372 B2	3/2012	Levin et al.
7,803,168 B2	9/2010	Gifford et al.	8,131,382 B2	3/2012	Asada
7,806,871 B2	10/2010	Li et al.	8,137,274 B2	3/2012	Weng et al.
7,811,265 B2	10/2010	Hering et al.	8,140,170 B2	3/2012	Rezai et al.
7,811,281 B1	10/2010	Rentrop	8,143,316 B2	3/2012	Ueno
7,811,313 B2	10/2010	Mon et al.	8,145,316 B2	3/2012	Deem et al.
7,816,511 B2	10/2010	Kawashima et al.	8,145,317 B2	3/2012	Demarais et al.
7,818,053 B2	10/2010	Kassab	8,150,518 B2	4/2012	Levin et al.
7,819,866 B2	10/2010	Bednarek	8,150,519 B2	4/2012	Demarais et al.
7,822,460 B2	10/2010	Halperin et al.	8,150,520 B2	4/2012	Demarais et al.
7,828,837 B2	11/2010	Khoury	8,152,830 B2	4/2012	Gumm
7,832,407 B2	11/2010	Gertner	8,162,933 B2	4/2012	Francischelli et al.
7,833,220 B2	11/2010	Mon et al.	8,175,711 B2	5/2012	Demarais et al.
7,837,676 B2	11/2010	Sinelnikov et al.	8,187,261 B2	5/2012	Watson
7,837,720 B2	11/2010	Mon	8,190,238 B2	5/2012	Moll et al.
7,841,978 B2	11/2010	Gertner	8,192,053 B2	6/2012	Owen et al.
7,846,157 B2	12/2010	Kozel	8,198,611 B2	6/2012	LaFontaine et al.
7,846,160 B2	12/2010	Payne et al.	8,214,056 B2	7/2012	Hoffer et al.
7,846,172 B2	12/2010	Makower	8,221,407 B2	7/2012	Phan et al.
7,849,860 B2	12/2010	Makower et al.	8,226,637 B2	7/2012	Satake
7,850,685 B2	12/2010	Kunis et al.	8,231,617 B2	7/2012	Satake
7,853,333 B2	12/2010	Demarais	8,241,217 B2	8/2012	Chiang et al.
7,854,734 B2	12/2010	Biggs et al.	8,257,724 B2	9/2012	Cromack et al.
7,857,756 B2	12/2010	Warren et al.	8,257,725 B2	9/2012	Cromack et al.
7,862,565 B2	1/2011	Eder et al.	8,260,397 B2	9/2012	Ruff et al.
7,863,897 B2	1/2011	Slocum, Jr. et al.	8,263,104 B2	9/2012	Ho et al.
7,869,854 B2	1/2011	Shachar et al.	8,273,023 B2	9/2012	Razavi
7,873,417 B2	1/2011	Demarais et al.	8,277,379 B2	10/2012	Lau et al.
7,887,538 B2	2/2011	Bleich et al.	8,287,524 B2	10/2012	Siegel
7,894,905 B2	2/2011	Pless et al.	8,287,532 B2	10/2012	Carroll et al.
7,896,873 B2	3/2011	Hiller et al.	8,292,881 B2	10/2012	Brannan et al.
7,901,400 B2	3/2011	Wham et al.	8,293,703 B2	10/2012	Averback et al.
7,901,402 B2	3/2011	Jones et al.	8,295,902 B2	10/2012	Salahieh et al.
7,901,420 B2	3/2011	Dunn	8,295,912 B2	10/2012	Gertner
7,905,862 B2	3/2011	Sampson	8,308,722 B2	11/2012	Ormsby et al.
7,918,850 B2	4/2011	Govari et al.	8,317,776 B2	11/2012	Ferren et al.
7,927,370 B2	4/2011	Webler et al.	8,317,810 B2	11/2012	Stangenes et al.
7,937,143 B2	5/2011	Demarais et al.	8,329,179 B2	12/2012	Ni et al.
7,938,830 B2	5/2011	Saadat et al.	8,336,705 B2	12/2012	Okahisa
7,942,874 B2	5/2011	Eder et al.	8,343,031 B2	1/2013	Gertner
7,942,928 B2	5/2011	Webler et al.	8,343,145 B2	1/2013	Brannan
7,946,976 B2	5/2011	Gertner	8,347,891 B2	1/2013	Demarais et al.
7,950,397 B2	5/2011	Thapliyal et al.	8,353,945 B2	1/2013	Andreas et al.
7,955,293 B2	6/2011	Nita et al.	8,364,237 B2	1/2013	Stone et al.
7,956,613 B2	6/2011	Wald	8,366,615 B2	2/2013	Razavi
7,959,627 B2	6/2011	Utley et al.	8,382,697 B2	2/2013	Brenneman et al.
7,962,854 B2	6/2011	Vance et al.	8,388,680 B2	3/2013	Starksen et al.
7,967,782 B2	6/2011	Laufer et al.	8,396,548 B2	3/2013	Perry et al.
7,967,808 B2	6/2011	Fitzgerald et al.	8,398,629 B2	3/2013	Thistle
7,972,327 B2	7/2011	Eberl et al.	8,401,667 B2	3/2013	Gustus et al.
7,972,330 B2	7/2011	Alejandro et al.	8,403,881 B2	3/2013	Ferren et al.
7,983,751 B2	7/2011	Zdeblick et al.	8,406,877 B2	3/2013	Smith et al.
8,001,976 B2	8/2011	Gertner	8,409,172 B2	4/2013	Moll et al.
			8,409,193 B2	4/2013	Young et al.
			8,409,195 B2	4/2013	Young
			8,418,362 B2	4/2013	Zerfas et al.
			8,452,988 B2	5/2013	Wang

(56)

References Cited

U.S. PATENT DOCUMENTS

8,454,594	B2	6/2013	Demarais et al.	2005/0096647	A1	5/2005	Steinke et al.
8,460,358	B2	6/2013	Andreas et al.	2005/0129616	A1	6/2005	Salcedo et al.
8,465,452	B2	6/2013	Kassab	2005/0137180	A1	6/2005	Robinson et al.
8,469,919	B2	6/2013	Ingle et al.	2005/0143817	A1	6/2005	Hunter et al.
8,473,067	B2	6/2013	Hastings et al.	2005/0148842	A1	7/2005	Wang et al.
8,480,663	B2	7/2013	Ingle et al.	2005/0149069	A1	7/2005	Bertolero et al.
8,485,992	B2	7/2013	Griffin et al.	2005/0149080	A1	7/2005	Hunter et al.
8,486,060	B2	7/2013	Kotmel et al.	2005/0149158	A1	7/2005	Hunter et al.
8,486,063	B2	7/2013	Werneth et al.	2005/0149173	A1	7/2005	Hunter et al.
8,488,591	B2	7/2013	Miali et al.	2005/0149175	A1	7/2005	Hunter et al.
2001/0007070	A1	7/2001	Stewart et al.	2005/0154277	A1	7/2005	Tang et al.
2001/0039419	A1	11/2001	Francischelli et al.	2005/0154445	A1	7/2005	Hunter et al.
2001/0051774	A1	12/2001	Littrup et al.	2005/0154453	A1	7/2005	Hunter et al.
2002/0022864	A1	2/2002	Mahvi et al.	2005/0154454	A1	7/2005	Hunter et al.
2002/0042639	A1	4/2002	Murphy-Chutorian et al.	2005/0165389	A1	7/2005	Swain et al.
2002/0045811	A1	4/2002	Kittrell et al.	2005/0165391	A1	7/2005	Maguire et al.
2002/0045890	A1	4/2002	Celliers et al.	2005/0165467	A1	7/2005	Hunter et al.
2002/0062146	A1	5/2002	Makower et al.	2005/0165488	A1	7/2005	Hunter et al.
2002/0065542	A1	5/2002	Lax et al.	2005/0175661	A1	8/2005	Hunter et al.
2002/0072686	A1	6/2002	Hoey et al.	2005/0175662	A1	8/2005	Hunter et al.
2002/0077592	A1	6/2002	Barry	2005/0175663	A1	8/2005	Hunter et al.
2002/0087151	A1	7/2002	Mody et al.	2005/0177103	A1	8/2005	Hunter et al.
2002/0087156	A1	7/2002	Maguire et al.	2005/0177225	A1	8/2005	Hunter et al.
2002/0095197	A1	7/2002	Lardo et al.	2005/0181004	A1	8/2005	Hunter et al.
2002/0107511	A1	8/2002	Collins et al.	2005/0181008	A1	8/2005	Hunter et al.
2002/0107536	A1	8/2002	Hussein	2005/0181011	A1	8/2005	Hunter et al.
2002/0143324	A1	10/2002	Edwards	2005/0181977	A1	8/2005	Hunter et al.
2002/0147480	A1	10/2002	Mamayek	2005/0182479	A1	8/2005	Bonsignore et al.
2002/0169444	A1	11/2002	Mest et al.	2005/0183728	A1	8/2005	Hunter et al.
2002/0198520	A1	12/2002	Coen et al.	2005/0186242	A1	8/2005	Hunter et al.
2003/0004510	A1	1/2003	Wham et al.	2005/0186243	A1	8/2005	Hunter et al.
2003/0028114	A1	2/2003	Casscells, III et al.	2005/0191331	A1	9/2005	Hunter et al.
2003/0060857	A1	3/2003	Perrson et al.	2005/0203410	A1	9/2005	Jenkins
2003/0060858	A1	3/2003	Kieval et al.	2005/0203434	A1	9/2005	Kassab
2003/0065317	A1	4/2003	Rudie et al.	2005/0203498	A1	9/2005	Mon et al.
2003/0069619	A1	4/2003	Fenn et al.	2005/0209587	A1	9/2005	Joye et al.
2003/0088189	A1	5/2003	Tu et al.	2005/0214205	A1	9/2005	Salcedo et al.
2003/0092995	A1	5/2003	Thompson	2005/0214207	A1	9/2005	Salcedo et al.
2003/0139689	A1	7/2003	Shturman et al.	2005/0214208	A1	9/2005	Salcedo et al.
2003/0195501	A1	10/2003	Sherman et al.	2005/0214209	A1	9/2005	Salcedo et al.
2003/0199747	A1	10/2003	Michlitsch et al.	2005/0214210	A1	9/2005	Salcedo et al.
2003/0212394	A1	11/2003	Pearson et al.	2005/0214268	A1	9/2005	Salcedo et al.
2003/0220639	A1	11/2003	Chapelson et al.	2005/0228286	A1	10/2005	Messerly et al.
2003/0229340	A1	12/2003	Sherry et al.	2005/0228415	A1	10/2005	Gertner
2003/0229384	A1	12/2003	Mon	2005/0228460	A1	10/2005	Levin et al.
2004/0006333	A1	1/2004	Arnold et al.	2005/0232921	A1	10/2005	Rosen et al.
2004/0010118	A1	1/2004	Zerhusen et al.	2005/0234312	A1	10/2005	Suzuki et al.
2004/0019348	A1	1/2004	Stevens et al.	2005/0245862	A1	11/2005	Seward
2004/0024371	A1	2/2004	Plicchi et al.	2005/0251116	A1	11/2005	Steinke et al.
2004/0043030	A1	3/2004	Griffiths et al.	2005/0252553	A1	11/2005	Ginggen
2004/0062852	A1	4/2004	Schroeder et al.	2005/0256398	A1	11/2005	Hastings et al.
2004/0064090	A1	4/2004	Keren et al.	2005/0267556	A1	12/2005	Shuros et al.
2004/0073206	A1	4/2004	Foley et al.	2005/0283195	A1	12/2005	Pastore et al.
2004/0088002	A1	5/2004	Boyle et al.	2006/0004323	A1	1/2006	Chang et al.
2004/0093055	A1	5/2004	Bartorelli et al.	2006/0018949	A1	1/2006	Ammon et al.
2004/0106871	A1	6/2004	Hunyor et al.	2006/0024564	A1	2/2006	Manclaw
2004/0111016	A1	6/2004	Casscells, III et al.	2006/0025765	A1	2/2006	Landman et al.
2004/0117032	A1	6/2004	Roth	2006/0062786	A1	3/2006	Salcedo et al.
2004/0147915	A1	7/2004	Hasebe	2006/0083194	A1	4/2006	Dhrimaj et al.
2004/0162555	A1	8/2004	Farley et al.	2006/0085054	A1	4/2006	Zikorus et al.
2004/0167506	A1	8/2004	Chen	2006/0089637	A1	4/2006	Werneth et al.
2004/0181165	A1	9/2004	Hoey et al.	2006/0089638	A1	4/2006	Carmel
2004/0186356	A1	9/2004	O'Malley et al.	2006/0095096	A1	5/2006	DeBenedictis et al.
2004/0186468	A1	9/2004	Edwards	2006/0106375	A1	5/2006	Werneth et al.
2004/0187875	A1	9/2004	He et al.	2006/0142790	A1	6/2006	Gertner
2004/0193211	A1	9/2004	Voegele et al.	2006/0147492	A1	7/2006	Hunter et al.
2004/0220556	A1	11/2004	Cooper et al.	2006/0167106	A1	7/2006	Zhang et al.
2004/0243022	A1	12/2004	Carney et al.	2006/0167498	A1	7/2006	DiLorenzo
2004/0243199	A1	12/2004	Mon et al.	2006/0171895	A1	8/2006	Bucay-Couto
2004/0253304	A1	12/2004	Gross et al.	2006/0184060	A1	8/2006	Belacazar et al.
2004/0267250	A1	12/2004	Yon et al.	2006/0184221	A1	8/2006	Stewart et al.
2005/0010095	A1	1/2005	Stewart et al.	2006/0195139	A1	8/2006	Gertner
2005/0010208	A1	1/2005	Winston et al.	2006/0206150	A1	9/2006	Demarais et al.
2005/0015125	A1	1/2005	Mioduski et al.	2006/0224153	A1	10/2006	Fischell et al.
2005/0080374	A1	4/2005	Esch et al.	2006/0235286	A1	10/2006	Stone et al.
				2006/0239921	A1	10/2006	Mangat et al.
				2006/0240070	A1	10/2006	Cromack et al.
				2006/0246143	A1	11/2006	Ege
				2006/0247266	A1	11/2006	Yamada et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2006/0247617 A1 *	11/2006	Danek et al.	606/41	2008/0161717 A1	7/2008	Gertner	
2006/0247760 A1	11/2006	Ganesan et al.		2008/0161801 A1	7/2008	Steinke et al.	
2006/0263393 A1	11/2006	Demopoulos et al.		2008/0171974 A1	7/2008	Lafontaine et al.	
2006/0269555 A1	11/2006	Salcedo et al.		2008/0172035 A1	7/2008	Starksen et al.	
2006/0271111 A1	11/2006	Demarais et al.		2008/0172104 A1	7/2008	Kieval et al.	
2006/0287644 A1	12/2006	Inganas et al.		2008/0188912 A1	8/2008	Stone et al.	
2007/0016184 A1	1/2007	Cropper et al.		2008/0188913 A1 *	8/2008	Stone et al.	607/99
2007/0016274 A1	1/2007	Boveja et al.		2008/0208162 A1	8/2008	Joshi	
2007/0027390 A1	2/2007	Maschke et al.		2008/0208169 A1	8/2008	Boyle et al.	
2007/0043077 A1	2/2007	Mewshaw et al.		2008/0213331 A1	9/2008	Gelfand et al.	
2007/0043409 A1	2/2007	Brian et al.		2008/0215117 A1	9/2008	Gross	
2007/0049924 A1	3/2007	Rahn		2008/0221448 A1	9/2008	Khuri-Yakub et al.	
2007/0066972 A1	3/2007	Ormsby et al.		2008/0234790 A1	9/2008	Bayer et al.	
2007/0073151 A1	3/2007	Lee		2008/0243091 A1	10/2008	Humphreys et al.	
2007/0078498 A1	4/2007	Rezai et al.		2008/0245371 A1	10/2008	Gruber	
2007/0093710 A1	4/2007	Maschke		2008/0249525 A1	10/2008	Lee et al.	
2007/0100405 A1	5/2007	Thompson et al.		2008/0249547 A1	10/2008	Dunn	
2007/0106247 A1	5/2007	Burnett et al.		2008/0255550 A1	10/2008	Bell	
2007/0112327 A1	5/2007	Yun et al.		2008/0255642 A1	10/2008	Zarins et al.	
2007/0118107 A1	5/2007	Francischelli et al.		2008/0262412 A1 *	10/2008	Atanasoska	A61N 1/325 604/20
2007/0129760 A1	6/2007	Demarais et al.		2008/0262489 A1	10/2008	Steinke	
2007/0129761 A1	6/2007	Demarais et al.		2008/0269664 A1 *	10/2008	Trovato et al.	604/20
2007/0135875 A1	6/2007	Demarais et al.		2008/0275484 A1	11/2008	Gertner	
2007/0149963 A1	6/2007	Matsukuma et al.		2008/0281312 A1	11/2008	Werneth et al.	
2007/0162109 A1	7/2007	Davila et al.		2008/0281347 A1	11/2008	Gertner	
2007/0173805 A1	7/2007	Weinberg et al.		2008/0287918 A1	11/2008	Rosenman et al.	
2007/0173899 A1	7/2007	Levin et al.		2008/0294037 A1	11/2008	Richter	
2007/0179496 A1	8/2007	Swoyer et al.		2008/0300618 A1	12/2008	Gertner	
2007/0197891 A1	8/2007	Shachar et al.		2008/0312644 A1	12/2008	Fourkas et al.	
2007/0203480 A1	8/2007	Mody et al.		2008/0312673 A1	12/2008	Viswanathan et al.	
2007/0207186 A1	9/2007	Scanlon et al.		2008/0317818 A1	12/2008	Griffith et al.	
2007/0208134 A1	9/2007	Hunter et al.		2009/0018486 A1	1/2009	Goren et al.	
2007/0208210 A1	9/2007	Gelfand et al.		2009/0018609 A1	1/2009	DiLorenzo	
2007/0208256 A1	9/2007	Marilla		2009/0024194 A1	1/2009	Arcot-Krishnamurthy et al.	
2007/0208301 A1	9/2007	Evard et al.		2009/0030312 A1	1/2009	Hadjicostis	
2007/0219576 A1	9/2007	Cangialosi		2009/0036948 A1	2/2009	Levin et al.	
2007/0225781 A1	9/2007	Saadat et al.		2009/0043372 A1	2/2009	Northrop et al.	
2007/0233170 A1	10/2007	Gertner		2009/0054082 A1	2/2009	Kim et al.	
2007/0239062 A1	10/2007	Chopra et al.		2009/0062873 A1	3/2009	Wu et al.	
2007/0244423 A1 *	10/2007	Zumeris	A61M 25/0017 604/22	2009/0069671 A1	3/2009	Anderson	
2007/0248639 A1	10/2007	Demopoulos et al.		2009/0074828 A1	3/2009	Alexis et al.	
2007/0249703 A1	10/2007	Mewshaw et al.		2009/0076409 A1	3/2009	Wu et al.	
2007/0254833 A1	11/2007	Hunter et al.		2009/0088735 A1	4/2009	Abboud et al.	
2007/0265687 A1	11/2007	Deem et al.		2009/0105631 A1	4/2009	Kieval	
2007/0278103 A1	12/2007	Hoerret et al.		2009/0112202 A1	4/2009	Young	
2007/0282302 A1	12/2007	Wachsman et al.		2009/0118620 A1	5/2009	Tgavalekos et al.	
2007/0292411 A1	12/2007	Salcedo et al.		2009/0118726 A1 *	5/2009	Auth	A61B 18/1492 606/33
2007/0293782 A1	12/2007	Marino		2009/0125099 A1	5/2009	Weber et al.	
2007/0299043 A1	12/2007	Hunter et al.		2009/0131798 A1	5/2009	Minar et al.	
2008/0004673 A1	1/2008	Rossing et al.		2009/0143640 A1	6/2009	Saadat et al.	
2008/0009927 A1	1/2008	Vilims		2009/0156988 A1	6/2009	Ferren et al.	
2008/0015501 A1	1/2008	Gertner		2009/0157057 A1	6/2009	Ferren et al.	
2008/0021408 A1	1/2008	Jacobsen et al.		2009/0157161 A1	6/2009	Desai et al.	
2008/0033049 A1	2/2008	Mewshaw		2009/0171333 A1	7/2009	Hon	
2008/0033465 A1 *	2/2008	Schmitz et al.	606/170	2009/0192558 A1	7/2009	Whitehurst et al.	
2008/0039746 A1	2/2008	Hissong et al.		2009/0198223 A1	8/2009	Thilwind et al.	
2008/0039830 A1	2/2008	Munger et al.		2009/0203962 A1	8/2009	Miller et al.	
2008/0051454 A1	2/2008	Wang		2009/0203993 A1	8/2009	Mangat et al.	
2008/0051812 A1 *	2/2008	Schmitz et al.	606/167	2009/0204170 A1	8/2009	Hastings et al.	
2008/0064957 A1	3/2008	Spence		2009/0210953 A1	8/2009	Moyer et al.	
2008/0071269 A1	3/2008	Hilario et al.		2009/0216317 A1	8/2009	Cromack et al.	
2008/0071306 A1	3/2008	Gertner		2009/0221955 A1	9/2009	Babaev	
2008/0082109 A1	4/2008	Moll et al.		2009/0226429 A1	9/2009	Salcedo et al.	
2008/0086072 A1	4/2008	Bonutti et al.		2009/0240249 A1	9/2009	Chan et al.	
2008/0091193 A1	4/2008	Kauphusman et al.		2009/0247933 A1	10/2009	Maor et al.	
2008/0097251 A1	4/2008	Babaev		2009/0247966 A1	10/2009	Gunn et al.	
2008/0097426 A1	4/2008	Root et al.		2009/0248012 A1	10/2009	Maor et al.	
2008/0108867 A1	5/2008	Zhou		2009/0253974 A1	10/2009	Rahme	
2008/0119879 A1	5/2008	Brenneman et al.		2009/0264755 A1	10/2009	Chen et al.	
2008/0125772 A1	5/2008	Stone et al.		2009/0270850 A1	10/2009	Zhou et al.	
2008/0132450 A1	6/2008	Lee et al.		2009/0281533 A1	11/2009	Ingle et al.	
2008/0140002 A1	6/2008	Ramzipoor et al.		2009/0287137 A1	11/2009	Crowley	
2008/0147002 A1	6/2008	Gertner		2009/0318749 A1	12/2009	Stolen et al.	
2008/0161662 A1	7/2008	Golijanin et al.		2010/0009267 A1	1/2010	Chase et al.	
				2010/0049191 A1	1/2010	Habib et al.	
				2010/0030061 A1	2/2010	Canfield et al.	
				2010/0048983 A1	2/2010	Ball et al.	

(56)

References Cited

U.S. PATENT DOCUMENTS

2010/0049099	A1	2/2010	Thapliyal et al.	2011/0264116	A1	10/2011	Kocur et al.
2010/0049186	A1	2/2010	Ingle et al.	2011/0270238	A1	11/2011	Rizq et al.
2010/0049188	A1	2/2010	Nelson et al.	2011/0306851	A1	12/2011	Wang
2010/0049283	A1	2/2010	Johnson	2011/0307034	A1	12/2011	Hastings et al.
2010/0069837	A1	3/2010	Rassat et al.	2011/0319809	A1	12/2011	Smith
2010/0076299	A1	3/2010	Gustus et al.	2012/0029496	A1	2/2012	Smith
2010/0076425	A1	3/2010	Carroux	2012/0029500	A1	2/2012	Jenson
2010/0087782	A1	4/2010	Ghaffari et al.	2012/0029505	A1	2/2012	Jenson
2010/0106005	A1	4/2010	Karczmar et al.	2012/0029509	A1	2/2012	Smith
2010/0114244	A1	5/2010	Manda et al.	2012/0029510	A1	2/2012	Haverkost
2010/0125268	A1	5/2010	Gustus et al.	2012/0029511	A1	2/2012	Smith et al.
2010/0130836	A1	5/2010	Malchano et al.	2012/0029512	A1	2/2012	Willard et al.
2010/0137860	A1	6/2010	Demarais et al.	2012/0029513	A1	2/2012	Smith et al.
2010/0137952	A1	6/2010	Demarais et al.	2012/0059241	A1	3/2012	Hastings et al.
2010/0160903	A1	6/2010	Krespi	2012/0059286	A1	3/2012	Hastings et al.
2010/0160906	A1	6/2010	Jarrard	2012/0065506	A1	3/2012	Smith
2010/0168624	A1	7/2010	Sliwa	2012/0065554	A1	3/2012	Pikus
2010/0168731	A1	7/2010	Wu et al.	2012/0095461	A1	4/2012	Herscher et al.
2010/0168739	A1	7/2010	Wu et al.	2012/0101413	A1	4/2012	Beetel et al.
2010/0174282	A1	7/2010	Demarais et al.	2012/0101490	A1	4/2012	Smith
2010/0191112	A1	7/2010	Demarais et al.	2012/0101538	A1	4/2012	Ballakur et al.
2010/0191232	A1	7/2010	Boveda	2012/0109021	A1	5/2012	Hastings et al.
2010/0204560	A1	8/2010	Salahieh et al.	2012/0116382	A1	5/2012	Ku et al.
2010/0217162	A1	8/2010	Hissong et al.	2012/0116383	A1	5/2012	Mauch et al.
2010/0222786	A1	9/2010	Kassab	2012/0116392	A1	5/2012	Willard
2010/0222851	A1	9/2010	Deem et al.	2012/0116438	A1	5/2012	Salahieh et al.
2010/0222854	A1	9/2010	Demarais et al.	2012/0116486	A1	5/2012	Naga et al.
2010/0228122	A1	9/2010	Keenan et al.	2012/0123243	A1	5/2012	Hastings
2010/0249604	A1	9/2010	Hastings et al.	2012/0123258	A1	5/2012	Willard
2010/0249773	A1	9/2010	Clark et al.	2012/0123261	A1	5/2012	Jenson et al.
2010/0256616	A1	10/2010	Katoh et al.	2012/0123303	A1	5/2012	Sogard et al.
2010/0268217	A1	10/2010	Habib	2012/0123406	A1	5/2012	Edmunds et al.
2010/0268307	A1	10/2010	Demarais et al.	2012/0130289	A1	5/2012	Demarais et al.
2010/0284927	A1	11/2010	Lu et al.	2012/0130345	A1	5/2012	Levin et al.
2010/0286684	A1	11/2010	Hata et al.	2012/0130359	A1	5/2012	Turovskiy
2010/0298821	A1	11/2010	Garbagnati	2012/0130360	A1	5/2012	Buckley et al.
2010/0305036	A1	12/2010	Barnes et al.	2012/0130362	A1	5/2012	Hastings et al.
2010/0312141	A1	12/2010	Keast et al.	2012/0130368	A1	5/2012	Jenson
2010/0324472	A1	12/2010	Wulfman	2012/0130458	A1	5/2012	Ryba et al.
2011/0009750	A1	1/2011	Taylor et al.	2012/0136344	A1	5/2012	Buckley et al.
2011/0021976	A1	1/2011	Li et al.	2012/0136349	A1	5/2012	Hastings
2011/0034832	A1	2/2011	Cioanta et al.	2012/0136350	A1	5/2012	Goshgarian et al.
2011/0040324	A1	2/2011	McCarthy et al.	2012/0136417	A1	5/2012	Buckley et al.
2011/0044942	A1	2/2011	Puri et al.	2012/0136418	A1	5/2012	Buckley et al.
2011/0060324	A1	3/2011	Wu et al.	2012/0143181	A1	6/2012	Demarais et al.
2011/0071400	A1	3/2011	Hastings et al.	2012/0143293	A1	6/2012	Mauch et al.
2011/0071401	A1	3/2011	Hastings et al.	2012/0143294	A1	6/2012	Clark et al.
2011/0077498	A1	3/2011	McDaniel	2012/0150267	A1	6/2012	Buckley et al.
2011/0092781	A1	4/2011	Gertner	2012/0157986	A1	6/2012	Stone et al.
2011/0092880	A1	4/2011	Gertner	2012/0157987	A1	6/2012	Steinke et al.
2011/0104061	A1	5/2011	Seward	2012/0157988	A1	6/2012	Stone et al.
2011/0112400	A1	5/2011	Emery et al.	2012/0157989	A1	6/2012	Stone et al.
2011/0118598	A1	5/2011	Gertner	2012/0157992	A1	6/2012	Smith et al.
2011/0118600	A1	5/2011	Gertner	2012/0157993	A1	6/2012	Jenson et al.
2011/0118726	A1	5/2011	De La Rama et al.	2012/0158101	A1	6/2012	Stone et al.
2011/0130708	A1	6/2011	Perry et al.	2012/0158104	A1	6/2012	Huynh et al.
2011/0137155	A1	6/2011	Weber et al.	2012/0172837	A1	7/2012	Demarais et al.
2011/0144479	A1	6/2011	Hastings et al.	2012/0172870	A1	7/2012	Jenson et al.
2011/0146673	A1	6/2011	Keast et al.	2012/0184952	A1	7/2012	Jenson et al.
2011/0166499	A1	7/2011	Demarais et al.	2012/0197198	A1	8/2012	Demarais et al.
2011/0178403	A1	7/2011	Weng et al.	2012/0197252	A1	8/2012	Deem et al.
2011/0178570	A1	7/2011	Demarais	2012/0232409	A1	9/2012	Stahmann et al.
2011/0200171	A1	8/2011	Beetel et al.	2012/0265066	A1	10/2012	Crow et al.
2011/0202098	A1	8/2011	Demarais et al.	2012/0265198	A1	10/2012	Crow et al.
2011/0207758	A1	8/2011	Sobotka et al.	2013/0012844	A1	1/2013	Demarais et al.
2011/0208096	A1	8/2011	Demarais et al.	2013/0012866	A1	1/2013	Deem et al.
2011/0257523	A1	10/2011	Hastings et al.	2013/0012867	A1	1/2013	Demarais et al.
2011/0257564	A1	10/2011	Demarais et al.	2013/0013024	A1	1/2013	Levin et al.
2011/0257622	A1	10/2011	Salahieh et al.	2013/0023865	A1	1/2013	Steinke et al.
2011/0257641	A1	10/2011	Hastings et al.	2013/0035681	A1	2/2013	Subramaniam et al.
2011/0257642	A1	10/2011	Griggs, III	2013/0066316	A1	3/2013	Steinke et al.
2011/0263921	A1	10/2011	Vrba et al.	2013/0085489	A1	4/2013	Fain et al.
2011/0264011	A1	10/2011	Wu et al.	2013/0090563	A1	4/2013	Weber
2011/0264075	A1	10/2011	Leung et al.	2013/0090578	A1	4/2013	Smith et al.
2011/0264086	A1	10/2011	Ingle	2013/0090647	A1	4/2013	Smith
				2013/0090649	A1	4/2013	Smith et al.
				2013/0090650	A1	4/2013	Jenson et al.
				2013/0090651	A1	4/2013	Smith
				2013/0090652	A1	4/2013	Jenson

(56)

References Cited

U.S. PATENT DOCUMENTS

2013/0096550 A1 4/2013 Hill
 2013/0096553 A1 4/2013 Hill et al.
 2013/0096554 A1 4/2013 Groff et al.
 2013/0096604 A1 4/2013 Hanson et al.
 2013/0110106 A1 5/2013 Richardson
 2013/0116687 A1 5/2013 Willard
 2013/0165764 A1 6/2013 Scheuermann et al.
 2013/0165844 A1 6/2013 Shuros et al.
 2013/0165916 A1 6/2013 Mathur et al.
 2013/0165917 A1 6/2013 Mathur et al.
 2013/0165920 A1 6/2013 Weber et al.
 2013/0165923 A1 6/2013 Mathur et al.
 2013/0165924 A1 6/2013 Mathur et al.
 2013/0165925 A1 6/2013 Mathur et al.
 2013/0165926 A1 6/2013 Mathur et al.
 2013/0165990 A1 6/2013 Mathur et al.
 2013/0172815 A1 7/2013 Perry et al.
 2013/0172872 A1 7/2013 Subramaniam et al.
 2013/0172877 A1 7/2013 Subramaniam et al.
 2013/0172878 A1 7/2013 Smith
 2013/0172879 A1 7/2013 Sutermeister
 2013/0172880 A1 7/2013 Willard
 2013/0172881 A1 7/2013 Hill et al.

FOREIGN PATENT DOCUMENTS

CN 102271607 A 12/2011
 DE 10038737 A1 2/2002
 DE 102005041601 A1 4/2007
 DE 102008048616 A1 4/2010
 EP 558297 A2 9/1993
 EP 647435 A1 4/1995
 EP 634910 B1 8/1997
 EP 868884 A2 10/1998
 EP 1005838 A1 6/2000
 EP 1053720 A1 11/2000
 EP 1064886 A1 1/2001
 EP 1180004 A1 2/2002
 EP 1181895 A2 2/2002
 EP 1297795 A1 6/2002
 EP 1264613 A2 12/2002
 EP 1286625 A1 3/2003
 EP 1332724 A1 8/2003
 EP 1335677 B1 8/2003
 EP 866675 B1 10/2003
 EP 1433448 A1 6/2004
 EP 1442719 A1 8/2004
 EP 1547537 A1 6/2005
 EP 1622531 2/2006
 EP 1634542 A1 3/2006
 EP 1698296 A1 6/2006
 EP 1709922 A1 10/2006
 EP 1874211 A2 1/2008
 EP 1906853 A2 4/2008
 EP 1946712 A1 7/2008
 EP 1961394 A2 8/2008
 EP 1715798 B1 4/2009
 EP 1620156 B1 7/2009
 EP 2076193 A2 7/2009
 EP 2091455 A2 8/2009
 EP 2092957 A1 8/2009
 EP 2197533 A1 6/2010
 EP 2208506 A1 7/2010
 EP 1579889 B1 8/2010
 EP 2241279 A1 10/2010
 EP 2092957 B1 1/2011
 EP 2329859 A1 6/2011
 EP 2349044 A1 8/2011
 EP 2027882 B1 10/2011
 EP 2378956 A2 10/2011
 EP 2037840 B1 12/2011
 EP 2204134 B1 4/2012
 EP 2320821 B1 10/2012
 GB 2313062 A 11/1997

GB 2453601 A 4/2009
 GB 2456301 A 7/2009
 JP 2003510126 A 3/2003
 WO 9103207 A1 3/1991
 WO 9117731 A1 11/1991
 WO 9320747 A1 10/1993
 WO 9320770 A2 10/1993
 WO 9418896 A1 9/1994
 WO 9428809 A1 12/1994
 WO 9501751 A1 1/1995
 WO 9531142 A1 11/1995
 WO 9634559 A1 11/1996
 WO 9703604 A1 2/1997
 WO 9717104 A1 5/1997
 WO 9720510 A1 6/1997
 WO 9732532 A1 9/1997
 WO 9740760 A1 11/1997
 WO 9745156 A2 12/1997
 WO 9818393 A1 5/1998
 WO 9834565 A1 8/1998
 WO 9835638 A1 8/1998
 WO 9840023 A1 9/1998
 WO 9858588 A1 12/1998
 WO 9900060 A1 1/1999
 WO 9916370 A1 4/1999
 WO 9921608 A1 5/1999
 WO 9934741 A1 7/1999
 WO 9944522 A1 9/1999
 WO 0010475 A1 3/2000
 WO 0047118 A1 8/2000
 WO 0051513 A1 9/2000
 WO 0059394 A1 10/2000
 WO 0062727 A1 10/2000
 WO 0064387 A1 11/2000
 WO 0069376 A1 11/2000
 WO 0072909 A1 12/2000
 WO 0122897 A1 4/2001
 WO 0137746 A1 5/2001
 WO 0187172 A1 5/2001
 WO 0187154 A1 11/2001
 WO 0195820 A1 12/2001
 WO 0228475 A1 4/2002
 WO 0239915 A1 5/2002
 WO 02058549 A1 8/2002
 WO 02080766 A2 10/2002
 WO 02087679 A2 11/2002
 WO 02089686 A1 11/2002
 WO 03026525 A1 4/2003
 WO 03077781 A1 9/2003
 WO 2004047659 A2 6/2004
 WO 2004049976 A1 6/2004
 WO 2004064606 A2 8/2004
 WO 2004069300 A2 8/2004
 WO 2004076146 A2 9/2004
 WO 2004098694 A1 11/2004
 WO 2004100813 A2 11/2004
 WO 2004105807 A2 12/2004
 WO 2004110258 A2 12/2004
 WO 2005007000 1/2005
 WO 2005037070 A2 4/2005
 WO 2005041748 A2 5/2005
 WO 2005074829 A1 8/2005
 WO 2006041881 A2 4/2006
 WO 2006105121 A2 10/2006
 WO 2006116198 A2 11/2006
 WO 2007011634 A1 1/2007
 WO 2007014063 A2 2/2007
 WO 2007047870 A2 4/2007
 WO 2007113865 A1 10/2007
 WO 2007135431 A2 11/2007
 WO 2007146215 A2 12/2007
 WO 2008003058 A2 1/2008
 WO 2008009972 A2 1/2008
 WO 2008010150 A2 1/2008
 WO 2008014465 A2 1/2008
 WO 2008036281 A2 3/2008
 WO 2008049084 A2 4/2008
 WO 2008061152 A2 5/2008
 WO 2008102363 A2 8/2008

(56)

References Cited

FOREIGN PATENT DOCUMENTS

WO	2009036471	A1	3/2009
WO	2009082635	A1	7/2009
WO	2009088678	A1	7/2009
WO	2009113064	A2	9/2009
WO	2009121017		10/2009
WO	2009121017	A1	10/2009
WO	2009137819	A1	11/2009
WO	2010042653	A1	4/2010
WO	2010048007	A1	4/2010
WO	2010056771	A1	5/2010
WO	2010057043	A1	5/2010
WO	2010067360	A2	6/2010
WO	2010070766	A1	6/2010
WO	2010099207	A1	9/2010
WO	2010102310	A2	9/2010
WO	2010120944	A2	10/2010
WO	2010134503	A1	11/2010
WO	2011005901	A2	1/2011
WO	2011053757	A1	5/2011
WO	2011053772	A1	5/2011
WO	2011055143	A2	5/2011
WO	2011060339	A1	5/2011
WO	2011091069	A1	7/2011
WO	2011126580	A2	10/2011
WO	2011130534	A2	10/2011
WO	2012019156	A1	2/2012
WO	2013049601	A2	4/2013

OTHER PUBLICATIONS

"IntraLuminal: Products," IntraLuminal Therapeutics, Inc., 2003, p. 1-9.

"Laser Catheter to Aid Coronary Surgery," TechTalk: MIT, Jan. 9, 1991, p. 1-4.

"Optical Coherence Tomography: Advantages of OCT," LightLab Imaging Technology.

"Optical Coherence Tomography: Image Gallery Cardiovascular Procedures," LightLab Imaging Technology.

"Optical Coherence Tomography: LightLab Imaging Starts US Cardiology Clinical Investigations," LightLab Imaging Technology, 2002.

"Optical Coherence Tomography: LightLab Sees Bright Prospects for Cardiac Application of OCT Technology," LightLab Imaging Technology, 2001, vol. 27, No. 35.

"Optical Coherence Tomography: What is OCT?," LightLab Imaging Technology.

"Optical Coherence Tomography: Why Use OCT?," LightLab Imaging Technology.

"Products—Functional Measurement," Volcano Functional Measurement Products US, Mar. 24, 2003, p. 1-2.

Brown et al., "Radiofrequency capacitive heaters: the effect of coupling medium resistivity on power absorption along a mouse leg," *Physics in Medicine and Biology*, 1993, p. 1-12, vol. 38.

Carrington, "Future of CVI: It's all about plaque: Identification of vulnerable lesions, not 'rusty pipes,' could become cornerstone of preventive cardiology," *Diagnostic Imaging*, 2001, p. 1-8.

Chen et al., "Percutaneous pulmonary artery denervation completely abolishes experimental pulmonary arterial hypertension in vivo," *EuroIntervention*, 2013, p. 1-8.

Cimino, "Preventing plaque attack," *Mass High Tech*, 2001, p. 1-2.

Dahm et al., "Relation of Degree of Laser Debulking of In-Stent Restenosis as a Predictor of Restenosis Rate," *The American Journal of Cardiology*, 2002, p. 68-70, vol. 90.

De Korte et al., "Characterization of Plaque Components With Intravascular Ultrasound Elastography in Human Femoral and Coronary Arteries in Vitro," *Circulation*, Aug. 8, 2000, p. 617-623.

Durney et al., "Radiofrequency Radiation Dosimetry Handbook," Oct. 1986, p. 1-2, Fourth Edition.

Durney et al., "Radiofrequency Radiation Dosimetry Handbook: Contents," Oct. 1986, p. 1-5, Fourth Edition.

Fournier-Desseux et al., "Assessment of 1-lead and 2-lead electrode patterns in electrical impedance endotomography," *Physiological Measurement*, 2005, p. 337-349, vol. 26, Institute of Physics Publishing.

Fram et al., "Feasibility of Radiofrequency Powered, Thermal Balloon Ablation of Atrioventricular Bypass Tracts Via the Coronary Sinus: In Vivo Canine Studies," *PACE*, Aug. 1995, p. 1518-1530, vol. 18.

Fram et al., "Low Pressure Radiofrequency Balloon Angioplasty: Evaluation in Porcine Peripheral Arteries," *JACC*, 1993, p. 1512-1521, vol. 21, No. 6, American College of Cardiology.

Fujimori et al., "Significant Prevention of In-Stent Restenosis by Evans Blue in Patients with Acute Myocardial Infarction," *American Heart Association*, 2002.

Fujita et al., "Sarpogrelate, An Antagonist of 5-HT_{2A} Receptor, Treatment Reduces Restenosis After Coronary Stenting," *American Heart Association*, 2002.

Gabriel, "Appendix A: Experimental Data," 1999, p. 1-21.

Gabriel, "Appendix C: Modeling the frequency dependence of the dielectric properties to a 4 dispersions spectrum," p. 1-6.

Gregory et al., "Liquid Core Light Guide for Laser Angioplasty," *The Journal of Quantum Electronics*, Dec. 1990, p. 2289-2296, vol. 26, No. 12.

Kaplan et al., "Healing after Arterial Dilatation with Radiofrequency Thermal and Nonthermal Balloon Angioplasty Systems," *Journal of Investigative Surgery*, 1993, p. 33-52, vol. 6.

Kolata, "New Studies Question Value of Opening Arteries," *The New York Times*, Mar. 21, 2004, p. 1-5.

Konings et al., "Development of an Intravascular Impedance Catheter for Detection of Fatty Lesions in Arteries," *IEEE Transactions on Medical Imaging*, Aug. 1997, p. 439-446, vol. 16, No. 4.

Kurtz et al., "Lamellar Refractive Surgery with Scanned Intrastromal Picosecond and Femtosecond Laser Pulses in Animal Eyes," *Journal of Refractive Surgery*, Sep./Oct. 1998, p. 541-548.

Lee et al., "Thermal Compression and Molding of Atherosclerotic Vascular Tissue With Use of Radiofrequency Energy: Implications for Radiofrequency Balloon Angioplasty," *JACC*, 1989, p. 1167-1175, vol. 13, No. 5, American College of Cardiology.

Lima et al., "Efficacy and Safety of Oral Sirolimus to Treat and Prevent In-Stent Restenosis: A Pilot Study Results," *American Heart Association*, 2002, p. 2929.

Lima et al., "Systemic Immunosuppression Inhibits In-Stent Coronary Intimal Proliferation in Renal Transplant Patients," *American Heart Association*, 2002, p. 2928.

Morice et al., "A Randomized Comparison of a Sirolimus-Eluting Stent With a Standard Stent for Coronary Revascularization," *The New England Journal of Medicine*, Jun. 6, 2012, p. 1773-1780, vol. 346, No. 23.

Muller-Leisse et al., "Effectiveness and Safety of Ultrasonic Atherosclerotic Plaque Ablation: In Vitro Investigation," *CardioVascular and Interventional Radiology*, 1993, p. 303-307, vol. 16.

Nair et al., "Regularized Autoregressive Analysis of Intravascular Ultrasound Backscatter: Improvement in Spatial Accuracy of Tissue Maps," *IEEE Transactions on Ultrasonics*, Apr. 2004, p. 420-431, vol. 51, No. 4.

Popma et al., "Percutaneous Coronary and Valvular Intervention," p. 1364-1405.

Resar et al., "Endoluminal Sealing of Vascular Wall Disruptions With Radiofrequency-Heated Balloon Angioplasty," *Catheterization and Cardiovascular Diagnosis*, 1993, p. 161-167, vol. 29.

Romer et al., "Histopathology of Human Coronary Atherosclerosis by Quantifying Its Chemical Composition With Raman Spectroscopy," *Circulation*, 1998, p. 878-885, vol. 97.

Schauerte et al., "Catheter Ablation of Cardiac Autonomic Nerves for Prevention of Vagal Atrial Fibrillation," *Circulation*, 2000, p. 2774-2780, vol. 102.

Scheller et al., "Intracoronary Paclitaxel Added to Contrast Media Inhibits In-Stent Restenosis of Porcine Coronary Arteries," *American Heart Association*, 2002, p. 2227.

Scheller et al., "Potential solutions to the current problem: coated balloon," *EuroIntervention*, 2008, p. C63-C66, vol. 4 (Supplement C).

(56)

References Cited

OTHER PUBLICATIONS

- Shaffer, "Scientific basis of laser energy," *Clinics in Sports Medicine*, 2002, p. 585-598, vol. 21.
- Shmatukha et al., "MRI temperature mapping during thermal balloon angioplasty," *Physics in Medicine and Biology*, 2006, p. N163-N171, vol. 51.
- Slager et al., "Vaporization of Atherosclerotic Plaques by Spark Erosion," *J Am Coll Cardiol*, 1985, p. 21-25.
- Stiles et al., "Simulated Characterization of Atherosclerotic Lesions in the Coronary Arteries by Measurement of Bioimpedance," *IEEE Transactions on Biomedical Engineering*, Jul. 2003, p. 916-921, vol. 50, No. 7.
- Suselbeck et al., "In vivo intravascular electric impedance spectroscopy using a new catheter with integrated microelectrodes," *Basic Res Cardiol*, 2005, p. 28-34, vol. 100.
- Suselbeck et al., "Intravascular electric impedance spectroscopy of atherosclerotic lesions using a new impedance catheter system," *Basic Res Cardiol*, 2005, p. 446-452, vol. 100.
- Tepe et al., "Local Delivery of Paclitaxel to Inhibit Restenosis during Angioplasty of the Leg," *The New England Journal of Medicine*, 2008, p. 689-699, vol. 358.
- Brown et al., "Radiofrequency capacitive heaters: the effect of coupling medium resistivity on power absorption along a mouse leg" *Phys Med Bio* 1993, 38:1-12 (abstract).
- Cardiovascular Technologies, Inc., "Heated Balloon Device Technology" [Presentation], 2007-2008, 11 pages total. Retrieved from: <<http://www.cvtechinc.com/pr/presoCVT_Heated_Balloon_Tech.pdf>>.
- Carrington, "Future of CVI: It's All About the Plaque." *Diagnostic Imaging Special Edition Forum* [online] [retrieved on Sep. 3, 2003] Retrieved from the Internet: <<http://dimag.com/specialedition/cardiacing.shtml>> 5 pages total.
- Cimino, "Preventing Plaque Attack", [online] [retrieved on Sep. 3, 2003] Retrieved from the Internet: <http://Masshigtech.com/displayarticledetail.asp?artid=52283&cat_id=10>, 3 pages total.
- Kaplan et al., "Healing after arterial dilatation with radiofrequency thermal and nonthermal balloon angioplasty systems," *J Invest Surg*, Jan.-Feb. 1993;6(1):33-52.
- Kolata, "New Studies Question Value of Opening Arteries", *New York Times* [online] [retrieved on Jan. 25, 2005]. Retrieved from the Internet: <<http://nytimes.com/2004/03/21/health/21HEAR.html?ei=5070&en=641bc03214e&e04-10-2009=11067>>, 5 pages total.
- Konings M K, et al., "Development of an Intravascular Impedance Catheter for Detection of Fatty Lesions in Arteries," *IEEE Transactions on Medical Imaging*, vol. 51, No. 4, Apr. 2004.
- Kurtz et al., "Lamellar Refractive Surgery with Scanned Intrastromal Picosecond and Femtosecond Laser Pulses in Animal Eyes", *J Refract Surg*, vol. 14, (Sep./Oct. 1998), pp. 541-548.
- Lightlab Imaging Technology, "Advantages of OCT", [online] [retrieved on Sep. 3, 2003]. Retrieved from the Internet: <<http://www.lightlabimaging.com/advantage.html>> 2 pages total.
- Lightlab Imaging Technology, "LightLab Imaging Starts US Cardiology Clinical Investigations", *LightLab Company Press Release*, [online] [retrieved on Sep. 3, 2003]. Retrieved from the Internet: <<http://www.lightlabimaging.com/press/cardtrails.html>> 2 pages total.
- Lightlab Imaging Technology, "What is OCT?", [online] [retrieved on Sep. 3, 2003]. Retrieved from the Internet: <<http://lightlabimaging.com/oct.html>> 2 pages total.
- Lightlab Imaging Technology, "Why use OCT?", [online] [retrieved on Sep. 3, 2003]. Retrieved from the Internet: <<http://lightlabimaging.com/whyoct.html>> 2 pages total.
- Lima et al., "Efficacy and Safety of Oral Sirolimus to Treat and Prevent In-Stent Restenosis: A Pilot Study Results", *Abstract #2929*, AHA (2002), 1 page total.
- Lima et al., "Systemic Immunosuppression Inhibits In-Stent Coronary Intimal Proliferation in Renal Transplant Patients", *Abstract #2928*, AHA (2002), 1 page total.
- MIT Techtalk, "Laser Catheter to Aid Coronary Surgery", Jan. 9, 1991 [online] [retrieved on Feb. 7, 2005]. Retrieved from the Internet: <<http://web.mit.edu/newsoffice/tU1991/jan09/24037.html>> 4 pages total.
- Morice et al., "A Randomized Comparison of a Sirolimus-Euting Stent With a Standard Stent for Coronary Revascularization", *N. Eng/ J Med*, vol. 346, No. 23, (Jun. 6, 2002), pp. 1773-1779.
- Moller et al., "Effectiveness and Safety of Ultrasonic Atherosclerotic Plaque Ablation: In Vitro Investigation", *CardioVas.Intervent. Radio/.*, (1993) 16: 303-307.
- Nair A, et al., "Regularized Autoregressive Analysis of Intravascular Ultrasound Backscatter: Improvement in Spatial Accuracy of Tissue Maps," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 51 No. 4, Apr. 2004.
- Popma et al., "Chapter 38—Percutaneous Coronary and Valvular Intervention", *Heart Disease: A Textbook of Cardiovascular Medicine*, 6th ed., (2001) W.B> Saunders Company, pp. 1364-1405.
- Romer et al., "Histopathology of Human Coronary Atherosclerosis by Quantifying Its Chemical Composition with Raman Spectroscopy," *Circulation* 97:878-885 (1998).
- Scheller, "Intracoronary Paclitaxel Added to Contrast Media Inhibits In-Stent Restenosis of Porcine Coronary Arteries", *Abstract #2227*, AHA (2002), 2 pages total.
- Scheller et al., "Potential Solutions to the Current Problem: Coated Balloon," *EuroIntervention*, Aug. 2008; 4 Suppl C: C63-66.
- Shaffer, "Scientific Basis of Laser Energy", *Clin Sports Med* 2002; 21 (4):585-598.
- Shmatukha A V, et al., "MRI temperature mapping during thermal balloon angioplasty," *Phys Med Bio* 51, (2006) N163-N171.
- Slager et al., "Vaporization of Atherosclerotic Plaques by Spark Erosion," *JAM Coli Cardiol*, vol. 5 (Jun. 1985) pp. 1382-1386.
- Stiles et al., "Simulated Charactization of Atherosclerotic Lesions in the Coronary Arteries by Measurement of Bioimpedance," *IEEE Transactions on Biomedical Engineering*, (Jul. 2003), 5(4):916-921.
- Suselbeck et al. "Intravascular electric impedance spectroscopy of atherosclerotic lesions using a new impedance system", *Basic Res Cardiol* (2005) 100:446-452.
- Suselbeck T, et al., "In vivo intravascular electrical impedance spectroscopy using a new catheter with integrated microelectrodes," *Basic Res Cardiol* 100:28-34 (2005).
- Tepe et al., "Local Delivery of Paclitaxel to Inhibit Restenosis During Angioplasty of the 41 Leg," *N Engl J Med*, Feb. 14, 2008; 358(7): 689-699; retrieved from the Internet: <<<http://content.nejm.org/cgi/reprint/358/7/689.pdf>>>.
- Van Den Berg, "Light Echoes Image the Human Body", *OLE*, Oct. 2001, pp. 35-37.
- Volcano Therapeutics, "Product—Functional Measurement", [online] [retrieved on Mar. 9, 2003]. Retrieved from the Internet: <http://www.volcanotherapeutics.com/pages/products/functional_measurement-us.html> 2 pages total.
- CardioVascular Technologies Inc., "Heated Balloon Device Technology," 11 pages, 2008.
- Strategic Business Development, Inc., "Thermal and Disruptive Angioplasty: A Physician's Guide," 8 pages, 1990.
- Zhang et al., "Non-contact Radio-Frequency Ablation for Obtaining Deeper Lesions," *IEEE Transaction on Biomedical Engineering*, vol. 50, No. 2, 6 pages, Feb. 2003.
- Lazebnik et al., "Tissue Strain Analytics Virtual Touch Tissue Imaging and Qualification," *Siemens Whitepaper*, Oct. 2008, 7 pages.
- Han et al., "Third-Generation Cryosurgery for Primary and Recurrent Prostate Cancer," *BJU International*, vol. 93, pp. 14-18.
- Zhou et al., "Mechanism Research of Cryoanalgesia," *Forefront Publishing Group*, 1995.
- Florete, "Cryoblative Procedure for Back Pain," *Jacksonville Medicine*, Oct. 1998, 10 pages.
- Stevenson, "Irrigated RF Ablation: Power Titration and Fluid Management for Optimal Safety Efficacy," 2005, 4 pages.
- Giliatt et al., "The Cause of Nerve Damage in Acute Compression," *Trans Am Neurol Assoc*, 1974: 99; 71-4.
- Omura et al., "A Mild Acute Compression Induces Neurapraxia in Rat Sciatic Nerve," *The International Journal of Neuroscience*, vol. 114 (12), pp. 1561-1572.

(56)

References Cited

OTHER PUBLICATIONS

Baun, "Interaction with Soft Tissue," Principles of General & Vascular Sonography, Chapter 2, pp. 23-24, Before Mar. 2012.

Blue Cross Blue Shield Medical Policy, "Surgery Section—MRI-Guided Focused Ultrasound (MRgFUS) for the Treatment of Uterine Fibroids and Other Tumors," 2005, 5 pages.

Gentry et al., "Combines 3D Intracardiac Echo and Ultrasound Ablation," Medical Imaging 2003: Ultrasonic and Signal Processing, vol. 5035, 2003, pp. 166-173.

Lafon et al., "Optimizing the Shape of Ultrasound Transducers for Interstitial Thermal Ablations," Med Phys. Mar. 2002; 29(3): 290-7 (abstract only).

G. Ter Haar, "Ultrasound Focal Beam Surgery," Ultrasound in Med. & Biol., 1995, vol. 21, No. 9, pp. 1089-1100.

Seip et al., "Transurethral High Intensity Focused Ultrasound: Catheter Based Prototypes and Experimental Results," IEEE Ultrasonics Symposium Proceeding, 2000, 4 pages.

Toytman et al., "Tissue Dissection with Ultrafast Laser Using Extended and Multiple Foci," SPIE Proceeding, Optical Interactions with Tissues and Cells XXI, vol. 7562, 2010, 10 pages.

Zhou et al., "Non-Thermal Ablation of Rabbit Liver VX2 Tumore by Pulsed High Intensity Focused Ultrasound Contrast Agent: Pathological Characteristics," World Journal of Gastroenterology, vol. 14(43), Nov. 21, 2008, pp. 6743-6747.

Dahm et al., "Relation of Degree of Laser Debulking of In-Stent Restenosis as a Predictor of Restenosis Rate", Am J Cardiol, 2002; 90(1): 68-70.

De Korte C L. et al., "Characterization of Plaque Components with Intravascular Ultrasound Elastography in Human Femoral and Coronary Arteries In Vitro," Circulation 2000;102:617-623.

Durney C., et al., Radiofrequency Radiation Dosimetry Handbook (with table of contents), Oct. 1986, 4th ed., 7 pages, Armstrong Laboratory (AFMC) Occupational and Environmental Health Directorate Radiofrequency Radiation Division, USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, <http://www.brooks.af.mii/AFRLIHED/hedr/reports/handbook/home.htm>.

Fournier-Desseux et al. "Assessment of 1-lead and 2-lead electrode patterns in electrical impedance endotomography", Physiol. Meas. (2005) 26:337-349.

Fujimori et al., "Significant Prevention of In-Stent Restenosis by Evans Blue in Patients with Acute Myocardial Infarction", Abstract #2925, AHA (2002), 1 page total.

Fujita, "Sarpogrelate, An Antagonist of 5-HT_{2a} Receptor Treatment Reduces Restenosis After Coronary Stenting", Abstract #2927, AHA (2002), 1 page total.

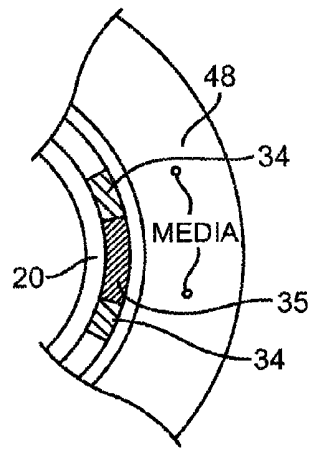
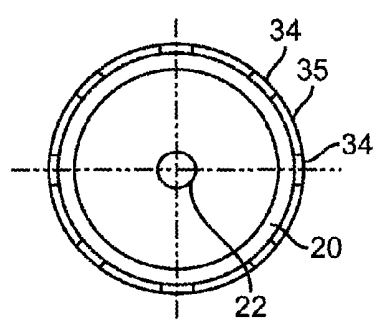
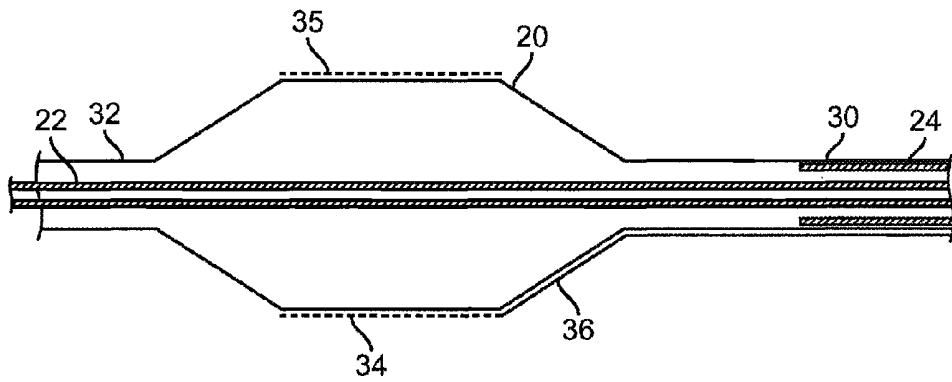
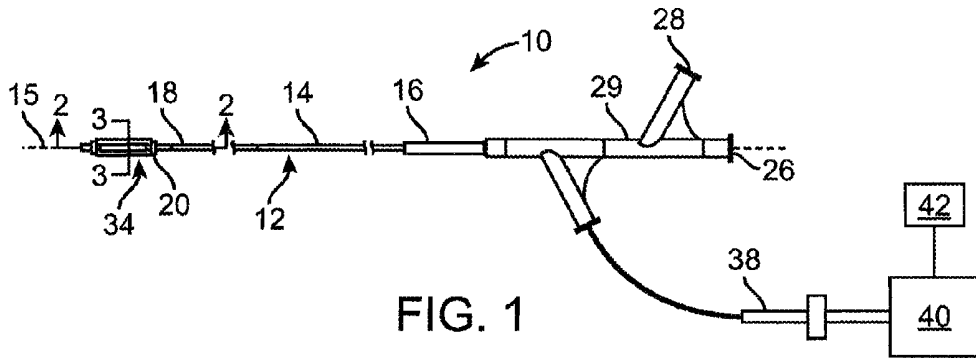
Gabriel C, et al., Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies (with table of contents), Jun. 1996, 17 pages, Armstrong Laboratory (AFMC) Occupational and Environmental Health Directorate Radiofrequency Radiation Division, USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks Air Force Base, <http://www.brooks.af.mii/AFRLIHED/hedr/reports/dielectric/ReporUReport.html>.

Gregory et al., "Liquid Core Light Guide for Laser Angioplasty", Journal of Quantum Electronics, vol. 26, No. 12, (Dec. 1990), pp. 2289-2296.

Intraluminal, Product description [online] [retrieved on Sep. 3, 2003] Retrieved from the Internet: <http://www.intraluminal.com/products/inde04-1-0-2009.html>> 1 page total.

US 8,398,630, 03/2013, Demarais et al. (withdrawn)

* cited by examiner



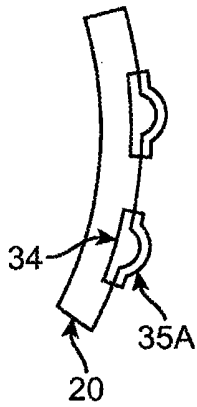


FIG. 4A

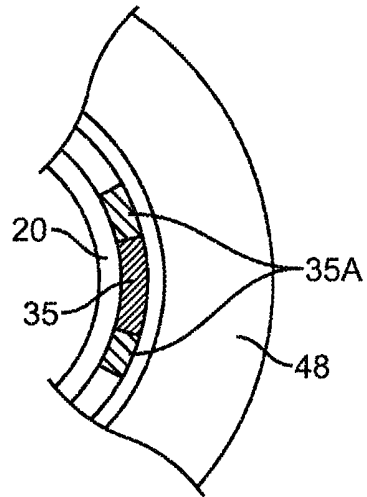


FIG. 4B

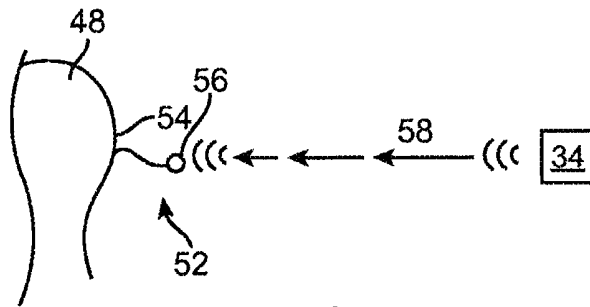


FIG. 5

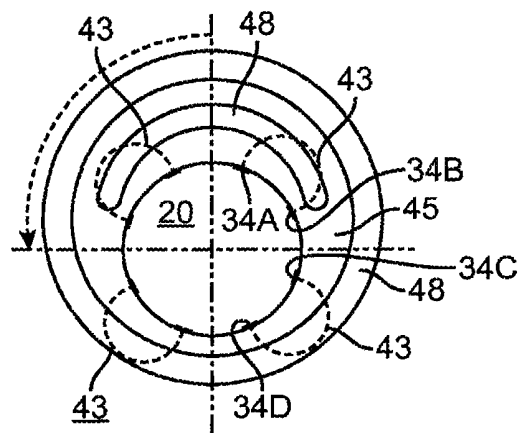
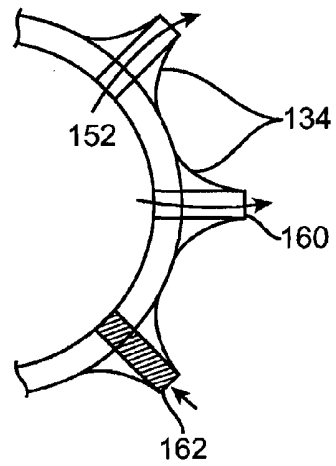
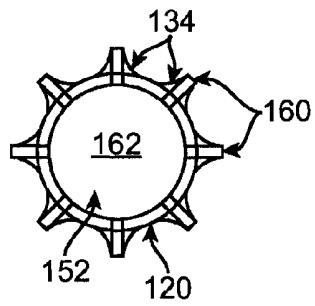
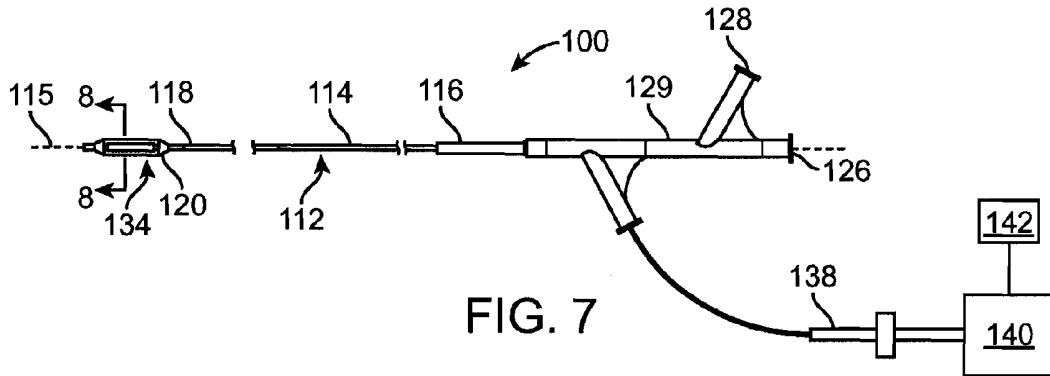


FIG. 6



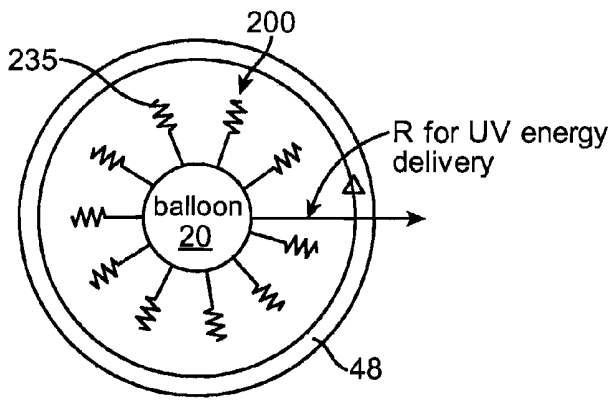


FIG. 9A

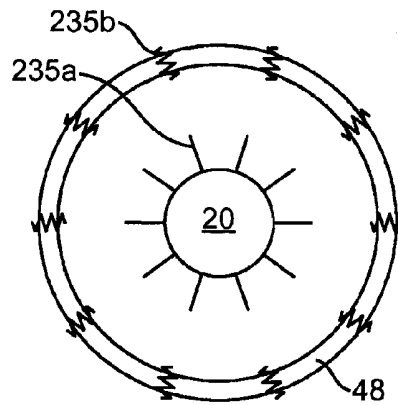


FIG. 9B

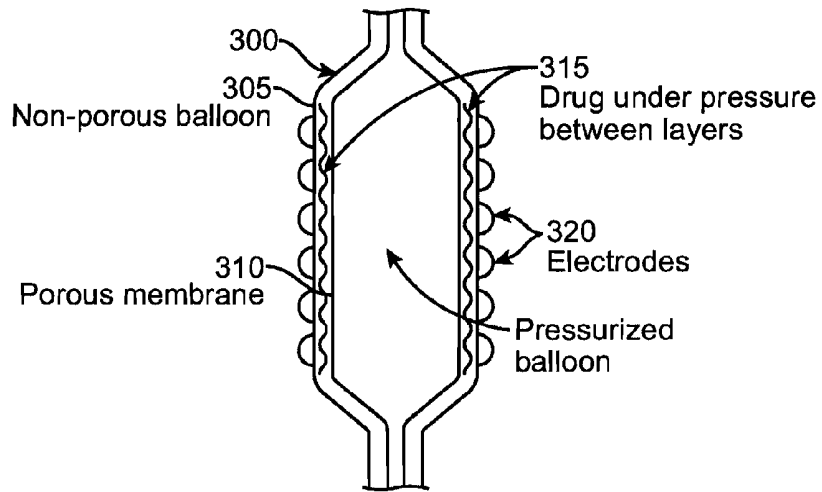


FIG. 10

SELECTIVE DRUG DELIVERY IN A LUMEN**CROSS-REFERENCES TO RELATED APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 12/616,720 filed Nov. 11, 2009, now U.S. Pat. No. 8,396,548; which claims the benefit under 35 USC 119(e) of U.S. Provisional Application No. 61/114,958 filed Nov. 14, 2008; the full disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

The present invention is generally related to medical devices, systems, and methods. In particular, the invention provides methods and systems for selective drug delivery to body tissue disposed about a lumen using a catheter-based treatment system.

Physicians use catheters to gain access to and repair interior tissues of the body, particularly within the lumens of the body such as blood vessels. For example, balloon angioplasty and other catheters often are used to open arteries that have been narrowed due to atherosclerotic disease. Balloon angioplasty is often effective at opening an occluded blood vessel, but the trauma associated with balloon dilation can impose significant injury, so that the benefits of balloon dilation may be limited in time.

Stenting, in conjunction with balloon dilation, is often the preferred treatment for atherosclerosis. In stenting, a collapsed metal framework is mounted on a balloon catheter which is introduced into the body. The stent is manipulated into the site of occlusion and expanded in place by the dilation of the underlying balloon. Stenting has gained widespread acceptance, and produces generally acceptable results in many cases. Along with treatment of blood vessels (particularly the coronary arteries), stents can also be used in treating many other tubular obstructions within the body, such as for treatment of reproductive, gastrointestinal, and pulmonary obstructions. Restenosis or a subsequent narrowing of the body lumen after stenting has occurred in a significant number of cases.

A variety of modified restenosis treatments or restenosis-inhibiting treatment modalities have also been proposed, including intravascular radiation, cryogenic treatments, ultrasound energy, and the like, often in combination with balloon angioplasty and/or stenting. While these and different approaches show varying degrees of promise for decreasing the subsequent degradation in blood flow following angioplasty and stenting, the trauma initially imposed on the tissues by angioplasty remains problematic.

A number of alternatives to stenting and balloon angioplasty have been proposed to open stenosed arteries. For example, a wide variety of atherectomy devices and techniques have been disclosed and attempted. Despite the disadvantages and limitations of angioplasty and stenting, atherectomy has not gained the widespread use and success rates of dilation-based approaches. More recently, still further disadvantages of dilation have come to light. These include the existence of vulnerable plaque, which can rupture and release materials that may cause myocardial infarction or heart attack.

More recently, drug coated stents (such as Johnson and Johnson's Cypher stent, the associated drug comprising Sirolimus) have demonstrated a markedly reduced restenosis rate, and others are developing and commercializing alternative drug eluting stents. While drug eluting stents appear to

offer significant promise for treatment of atherosclerosis in many patients, there remain many cases where stents either cannot be used or present significant disadvantages. Generally, stenting leaves an implant in the body. Such implants can present risks, including mechanical fatigue, corrosion, thrombus formation, and the like, particularly when removal of the implant is difficult and involves invasive surgery. Stenting may have additional disadvantages for treating diffuse artery disease, for treating bifurcations, for treating areas of the body susceptible to crush, and for treating arteries subject to torsion, elongation, and shortening.

In light of the above, it would be advantageous to provide methods and systems for selective fluid delivery to artery tissue that avoids the drawbacks associated with drug eluting stents and the devices described above.

BRIEF SUMMARY OF THE INVENTION

The present invention generally provides devices, systems, and methods for selective drug or fluid delivery to a body tissue being disposed about a lumen.

In a first aspect, the invention comprises a system for selective drug delivery to a body tissue being disposed about a lumen. The system includes an elongated flexible catheter body having a proximal end and a distal end with a radially expandable balloon near the distal end of the catheter body. An energy delivery surface disposed about the expandable balloon and a thermally changeable drug coating is coupled to the balloon, the energy delivery surface and the thermally changeable coating being oriented to be urged against the body tissue when the expandable balloon expands. An energy source is operatively coupled to the energy delivery surface configured to energize the energy delivery surface to heat and liquefy the thermally changeable coating to release the drug to the body tissue.

In another aspect, the invention comprises a method for selective drug delivery in a lumen. The method includes engaging a body tissue disposed about the lumen with an energy delivery surface and a thermally changeable coating having a releasable drug disposed on a radially expandable balloon near a distal end of a catheter when the expandable balloon expands, selectively energizing the energy delivery surface to heat and liquefy portions of the thermally changeable drug coating, and releasing a drug from the coating into the body tissue.

In many embodiments, the energy delivery surface comprises a plurality of electrodes, the energy source operatively coupled to the plurality of electrodes so as to selectively energize electrode pairs to heat and liquefy portions of the thermally changeable coating between the electrode pairs to release the drug to the body tissue. In many embodiments the body tissue of the lumen includes a diseased portion and select electrode pairs are energized to selectively heat the thermally changeable coating proximate the diseased portion.

In many embodiments, the energy delivery surface comprises a plurality of electrodes disposed about the expandable balloon so as to define a plurality of remodeling zones in the tissue when the balloon is expanded within the lumen, the electrodes are radially coupled with the tissue, and energy is transmitted between the electrodes and the tissue.

In many embodiments, further comprising a tissue analyzer configured to characterize the body tissue.

In many embodiments, the energy delivery surface is energized to heat the thermally changeable coating to release the drug in responses to the characterized body tissue.

In many embodiments, the body tissue of the lumen includes a diseased portion and select electrode pairs are

energized to selectively heat the thermally changeable coating proximate the diseased portion.

In many embodiments, the energy delivery surface is energized to heat the body tissue in combination with the drug delivery.

In many embodiments, the thermally changeable drug coating includes more than one drug.

In many embodiments, the drug is selected from at least one of, a therapeutic fluid, an anesthetic drug, a therapeutic drug, a small molecule, a gene therapeutic compound, an anti-thrombolytic agent, a lubricant (to allow higher temperatures without sticking), an electrically conductive compound to lower the impedance at the electrode, an electrically insulating compound to prevent treatment to tissue that does not need treatment, an electrically conductive compound that is intended to migrate through the endothelial layers of tissue to carry energy to the interstitial layers, or a combination of the above.

In another aspect, the invention comprises a catheter system for drug delivery to a body tissue being disposed about a lumen. The system includes an elongated flexible catheter body having a proximal end and a distal end, a radially expandable balloon near the distal end of the catheter body, and an energy delivery surface disposed about the expandable balloon. A plurality of biomolecules having a thermally releasable drug portion and an inert portion covalently bound to the balloon and an energy source operatively coupled to the energy delivery surface so as to heat the biomolecules to release the drug portion to the body tissue.

In another aspect, the invention comprises a method for fluid delivery in a lumen. The method includes engaging a body tissue disposed about the lumen with an energy delivery surface and a plurality of biomolecules having a thermally releasable drug portion and an inert portion covalently bound to the balloon near a distal end of a catheter when the expandable balloon expands, energizing the energy delivery surface to heat the biomolecules, and releasing the drug portion from the biomolecules into the body tissue.

In many embodiments, the energy delivery surface comprises a plurality of electrodes, the energy source operatively coupled to the plurality of electrodes so as to selectively energize electrode pairs to heat the biomolecules between the electrode pairs to release the drug portion to the body tissue.

In many embodiments, the body tissue of the lumen includes a diseased portion and select electrode pairs are energized to selectively heat the biomolecules proximate to the diseased portion.

In many embodiments, the energy delivery surface and biomolecules are oriented to be urged against the body tissue when the expandable balloon expands.

In many embodiments, further comprising a tissue analyzer configured to characterize the body tissue and the energy delivery surface is energized to heat the biomolecules to release the drug portion in responses to the characterized body tissue.

In many embodiments, the energy delivery surface is further energized to heat the body tissue in combination with the drug delivery.

In many embodiments, the biomolecules include more than one releasable drug.

In many embodiments, the drug portion is selected from at least one of, a therapeutic fluid, an anesthetic drug, a therapeutic drug, a small molecule, a gene therapeutic compound, an anti-thrombolytic agent, a lubricant (to allow higher temperatures without sticking), an electrically conductive compound to lower the impedance at the electrode, an electrically insulating compound to prevent treatment to tissue that does

not need treatment, an electrically conductive compound that is intended to migrate through the endothelial layers of tissue to carry energy to the interstitial layers, or a combination of the above.

In another aspect, the invention comprises a catheter system for selective fluid delivery to a body tissue being disposed about a lumen. The system includes an elongated flexible catheter body having a proximal end and a distal end, a radially expandable structure near the distal end of the catheter body, a plurality of fluid delivery channels oriented to be urged against the body tissue when the expandable structure expands, the fluid delivery channels being initially blocked with a thermally changeable material, and an energy source connector operatively coupled to the fluid delivery channels so as to heat and liquefy the thermally changeable material to selectively open one or more of the fluid delivery channels for fluid release.

In another aspect, the invention comprises a catheter system for selective fluid delivery to a body tissue being disposed about a lumen. The system includes an elongated flexible catheter body having a proximal end and a distal end, a radially expandable structure near the distal end of the catheter body, a plurality of fluid delivery channels oriented to be urged against the body tissue of the lumen when the expandable structure expands, the fluid delivery channels being initially closed, and a plurality of micro-electromechanical systems (MEMS) coupled to the fluid delivery channels to selectively open one or more fluid delivery channels and release a fluid in the lumen.

In another aspect, the invention comprises a method for selective fluid delivery in a lumen. The method includes engaging a body tissue disposed about the lumen with a plurality of fluid delivery channels on a radially expandable structure near a distal end of a catheter when the expandable structure expands, selectively opening one or more fluid delivery channels, and releasing a fluid from the select fluid delivery channels into the lumen.

In many embodiments, the plurality of fluid delivery channels protrude from the expandable structure to penetrate the body tissue of the lumen.

In many embodiments, further comprising a tissue analyzer configured to characterize the body tissue to identify body tissue to be treated and selectively opening or closing one or more fluid delivery channels in responses to the characterized body tissue to treat the identified body tissue.

In many embodiments, the fluid delivery channels can be selectively energized to selectively open one or more fluid delivery channels in responses to the characterized body tissue.

In many embodiments, the radially expandable structure comprises a balloon and the fluid delivery channels are mounted on a circumference of the balloon.

In many embodiments, the radially expandable structure comprises an expandable basket and the fluid delivery channels are mounted on a circumference of the basket.

In many embodiments, the body tissue of the lumen includes a diseased portion and select electrodes are energized to selectively open one or more fluid delivery channels proximate the diseased portion.

In many embodiments, select electrodes are energized to heat the body tissue in conjunction with the release of the fluid in the lumen.

In many embodiments, selectively opening one or more fluid delivery channels comprises selectively energizing electrodes coupled to the select fluid delivery channels to heat the select fluid delivery channels to liquefy a thermal material initially closing the fluid delivery channel.

In many embodiments, the fluid is selected from at least one of, ceramide, suramin, rapamycin, paclitaxel, sirolimus, zotarolimus, everolimus, a therapeutic fluid, an anesthetic drug, a therapeutic drug, a small molecule, a gene therapeutic compound, an anti-thrombolytic agent, a lubricant (to allow higher temperatures without sticking), an electrically conductive compound to lower the impedance at an electrode, an electrically insulating compound to prevent treatment to tissue that does not need treatment, an electrically conductive compound that is intended to migrate through the endothelial layers of tissue to carry energy to the interstitial layers, or a combination of the above.

In yet another aspect, the invention comprises a method for selective fluid delivery in a lumen. The method includes engaging a body tissue disposed about the lumen with a plurality of fluid delivery channels on a radially expandable structure near a distal end of a catheter when the expandable structure expands, the balloon material is a membrane of a fixed pore size, and adding energy or heat to the fluid adjacent to the balloon surface allows the specific molecules to be passed through the membrane at the specific region for the specific time by virtue of the energy/heat source being switched on or off.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates one embodiment of a catheter system having a coating for selective drug delivery to a body tissue being disposed about a lumen.

FIG. 2 schematically illustrates one embodiment of an inflatable balloon for use in the catheter system of FIG. 1.

FIG. 3A schematically illustrates a cross-sectional view and 3B is an enlarged view of the balloon of FIG. 2.

FIGS. 4A and 4B schematically illustrates coatings covering the electrodes.

FIG. 5 schematically illustrates the used of aptamers in treating tissue.

FIG. 6 schematically illustrates placement of electrode pairs for use in bipolar energy treatment before, during, or after drug delivery.

FIG. 7 schematically illustrates another embodiment of a catheter system having fluid delivery channels for selective fluid delivery to a body tissue being disposed about a lumen.

FIG. 8A schematically illustrates a cross-section and FIG. 8B is an enlarged section of the balloon in FIG. 7 showing fluid delivery channels through the balloon coupled to electrodes mounted on a surface of the balloon.

FIGS. 9A and 9B schematically illustrate cross-sectional views showing tissue treatment using biomolecules having a thermally releasable active portion and an inert portion coupled by covalent bond to a balloon surface.

FIG. 10 schematically illustrates another embodiment of a balloon having a membrane for selective drug delivery to a body tissue being disposed about a lumen.

DETAILED DESCRIPTION OF THE INVENTION

Many therapies have been developed to replace or improve upon traditional balloon angioplasty and stents. The alternative devices described in the BACKGROUND OF THE INVENTION either cut, ablate, or vaporize diseased tissue in an artery. For example, laser devices vaporize plaque and flush it downstream. Atherectomy devices excise plaque and suck it out of the body. Cutting balloons incise the artery wall, damaging the tissue. Even a simple angioplasty balloon does trauma to the tissue. It would be advantageous to provide treatments to body tissue that do not cut, ablate, or vaporize.

The present invention discloses systems and methods for selective delivery of a fluid to body tissue in a lumen, in particular, selective drug delivery in a lumen. Selective delivery may also control when and where the drug is delivered, and the amount of drug delivered.

While the disclosure focuses on drug delivery, such as, ceramide, suramin, rapamycin, paclitaxel, sirolimus, zotarolimus, everolimus, a drug (anesthetic or therapeutic), many other suitable fluids may be also be delivered to body tissue, for example, a therapeutic fluid, a small molecule, a gene therapeutic compound, an anti-thrombolytic agent, a lubricant (to allow higher temperatures without sticking), an electrically conductive compound to lower the impedance at the electrode, an electrically insulating compound to prevent treatment to tissue that does not need treatment, an electrically conductive compound that is intended to migrate through the endothelial layers of tissue to carry energy to the interstitial layers, or a combination of the above.

In some embodiments of the present invention, a drug is incorporated into a coating on a balloon catheter that is thermally released once inside the lumen to selectively treat the tissue. In other embodiments, a fluid or drug may be delivered through fluid delivery channels in a catheter system to selectively treat the tissue. In still other embodiments, multiple fluids or drugs may be delivered as part of a coating, through the fluid delivery channels, by thermal osmosis through a membrane, or any combination thereof. In some embodiments the drug may be delivered at one tissue site, while other embodiments portions of the drug to different sites.

Some embodiments of the present invention use heating to release the drug coating. Other embodiments combine fluid or drug delivery with heating of the tissue before, during or after delivery to the tissue. Devices for heating artery tissue using RF, ultrasound, microwave and laser energies have been disclosed in co-pending U.S. patent application Ser. Nos. 11/975,474, 11/975,383, 11/122,263 and U.S. Provisional Application No. 61/099,155, the full disclosures of which are incorporated herein by reference.

Drug Delivery During an Angioplasty Procedure

Some embodiments of the present invention provide systems and methods for drug delivery in a lumen in combination with heating during an angioplasty procedure. While drugs are disclosed, proteins, cells and/or molecules may also be delivered (discussed below). The angioplasty procedure itself is the procedure that will open the lumen. The heating will cause softening and shrinking of a lesion, enabling the plaque to reshape easily around the balloon while avoiding stretching of the vessel thus avoiding injury to the vessel. The drug will be released during the angioplasty procedure and the heating process. Drug delivery treatment during an angioplasty procedure will be a combination of:

Pressure—due to the balloon in order to open the lumen.

The pressure may be standard angioplasty dilation pressures of 10-16 atmospheres or may be more gentle dilation pressures of 6 atmospheres or less, and possibly as low as 1 to 2 atmospheres.

Heating—due to the RF energy in order to soften and shrink the lesion. Heating may also have other benefits related to the drug or drug delivery (discussed below).

Drug/Protein/Cell/Molecule—which will be released during the procedure.

The Drug/Molecule/Protein/Cell element can be built of one component, or in combination of others such as:

1. Drugs: any molecule which will enable prevention or reduction of smooth muscle cell (SMC) proliferation and/or migration from the media to the intima, for example: ceramide, suramin, rapamycin and paclitaxel. The heating of the

tissue may have a key role in helping deliver the drug into the lesion or tissue, and deeper into the media.

2. Proteins: proteins such as anti-inflammatory proteins, antibodies and other kinds of proteins which will enable the reduction and healing of the inflammation inside the lesion, or enable prevention or reduction of SMC proliferation and migration. We can also use protein that will induce cell apoptosis or oncosis. The heating may have a key role in activating these proteins during the treatment, and if heated quickly during the procedure, enabling the maximum time exposure of the tissue to the proteins. In order to make sure that the proteins will be activated during the procedure, one should take into account the half-life of a protein. The half-life of a protein is the time it takes before any half of the protein pool for that particular protein is left. For human proteins, it ranges from minutes to 80 hours. In order to use proteins eluting balloon, the balloon needs to be maintained in lower temperature (<0° C.), so the proteins won't be ruined and destroyed. Several of the proteins that may be combined to a molecule named Adenosine-5'-triphosphate (ATP). ATP is a multifunctional nucleotide that is important as a "molecular currency" of intracellular energy transfer. In one example, the balloon is covered with the protein and the electrodes are covered with ATP (or the opposite) and the protein will be released with the balloon inflation, and the ATP will be released when the energy will be emitted from the electrodes (or the opposite).

3. Cells: coating the balloon with cells such as endothelium, or any other type of cell which can migrate to the lesion during the procedure, where they will release proteins or antibodies to heal the inflammation or prevent SMC proliferation and migration. The heat in this case is also to activate the cells during the procedure.

4. Molecules or proteins that can be attached or become activated when attached to heat shock proteins (HSP). HSP are a group of proteins whose expression is increased when the cells are exposed to elevated temperatures or other stress. For example, HSP27 functions in smooth muscle cells (SMC) migration. In this case the RF energy and the heating will result in elevation of HSP27 inside the SMC, so we can use any drug/molecule or protein directly to the SMC by using anti-HSP27 antibody. The concept is to use the heat and the outcomes of the heat in order to use other molecules or proteins to bind, degrade, inhibit or activate other proteins or cells in the lesion and in the media, in order to prevent restenosis.

Drug Delivery Coatings

FIG. 1 shows one embodiment of a catheter system 10 having a releasable coating for selective drug delivery to a body tissue being disposed about a lumen. The catheter system 10 includes a balloon catheter 12 having a catheter body 14 with a proximal end 16 and a distal end 18. Catheter body 14 is flexible and defines a catheter axis 15, and may include one or more lumens, such as a guidewire lumen 22 and an inflation lumen 24. Catheter 12 includes an inflatable balloon 20 adjacent distal end 18 and a housing 29 adjacent proximal end 16. Housing 29 includes a first connector 26 in communication with guidewire lumen 22 and a second connector 28 in fluid communication with inflation lumen 24. Inflation lumen 24 extends between balloon 20 and second connector 28. Both first and second connectors 26, 28 may optionally comprise a standard connector, such as a Luer-Loc™ connector. A distal tip may include an integral tip valve to allow passage of guidewires, and the like.

Housing 29 also accommodates an electrical connector 38. Connector 38 includes a plurality of electrical connections, each electrically coupled to electrodes 34 via conductors 36. This allows electrodes 34 to be easily energized, the elec-

trodes often being energized by a controller 40 and power source 42, such as RF energy. In one embodiment, electrical connector 38 is coupled to an RF generator via a controller 40, with controller 40 allowing energy to be selectively directed to electrodes 34. While RF energy is disclosed, other suitable energy sources may be used, such as microwave energy, ultrasound energy, or laser energy, each having energy delivery portions configured to deliver the desired energy. See co-pending U.S. Provisional Application No. 61/099,155, the full disclosures of which are incorporated herein by reference.

In some embodiments, controller 40 may include a processor or be coupled to a processor to control or record treatment. The processor will typically comprise computer hardware and/or software, often including one or more programmable processor unit running machine readable program instructions or code for implementing some or all of one or more of the methods described herein. The code will often be embodied in a tangible media such as a memory (optionally a read only memory, a random access memory, a non-volatile memory, or the like) and/or a recording media (such as a floppy disk, a hard drive, a CD, a DVD, a non-volatile solid-state memory card, or the like). The code and/or associated data and signals may also be transmitted to or from the processor via a network connection (such as a wireless network, an Ethernet, an internet, an intranet, or the like), and some or all of the code may also be transmitted between components of catheter system 10 and within processor via one or more bus, and appropriate standard or proprietary communications cards, connectors, cables, and the like will often be included in the processor. Processor will often be configured to perform the calculations and signal transmission steps described herein at least in part by programming the processor with the software code, which may be written as a single program, a series of separate subroutines or related programs, or the like. The processor may comprise standard or proprietary digital and/or analog signal processing hardware, software, and/or firmware, and will typically have sufficient processing power to perform the calculations described herein during treatment of the patient, the processor optionally comprising a personal computer, a notebook computer, a tablet computer, a proprietary processing unit, or a combination thereof. Standard or proprietary input devices (such as a mouse, keyboard, touchscreen, joystick, etc.) and output devices (such as a printer, speakers, display, etc.) associated with modern computer systems may also be included, and processors having a plurality of processing units (or even separate computers) may be employed in a wide range of centralized or distributed data processing architectures.

Balloon 20 is illustrated in more detail in FIG. 2. Balloon 20 generally includes a proximal portion 30 coupled to inflation lumen 24 and a distal portion 32 coupled to guidewire lumen 22. Balloon 20 expands radially when inflated with a fluid or a gas. In some embodiments, the fluid or gas may be non-conductive and/or cooled. In some embodiments, balloon 20 may be a low pressure balloon pressurized to contact the artery tissue. In other embodiments, balloon 20 is an angioplasty balloon capable of higher pressure to both heat the artery tissue and expand the artery lumen. Balloon 20 may comprise a compliant or non-compliant balloon having helical folds to facilitate reconfiguring the balloon from a radially expanded, inflated configuration to a low profile configuration, particularly for removal after use.

Electrodes 34 are mounted on a surface of balloon 20, with associated conductors 36 extending proximally from the electrodes. Electrodes 34 may be arranged in many different patterns or arrays on balloon 20. The system may be used for

monopolar or bipolar application of energy. For delivery of bipolar energy, adjacent electrodes are axially offset to allow bipolar energy to be directed between adjacent circumferential (axially offset) electrodes. In other embodiments, electrodes may be arranged in bands around the balloon to allow bipolar energy to be directed between adjacent distal and proximal electrodes.

A coating **35** is coupled to the balloon **20** and positioned between electrodes **34**, such as shown in FIGS. **3A** and **3B**. Coating **35** includes a fluid or drug to be delivered to the targeted tissue. It is envisioned that the coating will be thermally activated and configured to be released from the balloon surface at a temperature above body temperature (greater than 37 C). The idea is to have the energy delivery or heat, change the phase of a coating compound from a solid to a liquid, and releases the drug. This temperature increase involves activating electrodes **34** using RF energy. As the energy is increased, the coating **35** between the electrodes **34** is heated and released thermally to the local tissue **48**. Coating **35** is durable or flexible such that it can be folded with the balloon **20** without separation or delamination. This mechanism could release small or large molecular drug or pharmaceutical product. The drug could be in a solid gel form.

In some embodiments, a second coating **35A** may be used to cover electrodes **34**, such as shown in FIG. **4A**. Second coating **35A** may be an insulating coating on the electrodes **34**. The second coating **35A** would be used when treating inside a metallic object in the lumen, such as a stent, because if the electrodes **34** come in contact with metal, they may short and the treatment will end. If the electrodes **34** are coated with a material with electrical properties such that the electrodes can not be shorted with metallic objects, the treatment can continue even when in contact with metal objects. This would allow catheter system **10** to treat inside objects like stents. Second coating **35A** may also act to insulate electrodes **34** from tissue **48**, shown in FIG. **4B**, which stops/prohibits energy flow through tissue **48** and sends the energy through coating **35**, heating only the coating **35** between the electrodes **34**, releasing the drug to the tissue **48**. The second coating **35A** may also include a different drug than coating **35**.

Many types of drugs may be included in the coatings. For example, the coating may include drugs currently used in drug eluting stents, such as sirolimus (used in the Cypher™ stent), paclitaxel (used in the Taxus™ stent), zotarolimus (used in the Endeavour™ stent) and everolimus (used in the Xience V™ stent).

Some embodiments of the present invention may include aptamers **52** coated to the balloon **20** using a substrate that breaks down readily when heated, such as when the RF energy source is activated. Aptamers can be engineered to bind very specifically to various molecular targets such as small molecules, proteins, nucleic acids, and even cells, tissues and organisms. The aptamers **52** could be synthesized to bind **54** with desired tissue **48** to be treated, such as plaque, within the lumen or artery.

While the catheter system **10** is not powered and the balloon **20** deflated, the coating **35** with aptamers **52** would remain on the balloon **20**. Once the balloon **20** is inflated and the energy unit turned on, the coating is released and the aptamers **52** bind to the desired tissue, such as shown in FIG. **5**. In some embodiments, aptamers **52** would be conjugated to a microscopic bead **56** that is highly receptive to the energy **58**, such as RF energy, emitted by the catheter system **10**. The beads **56** convert the RF energy to thermal energy directly and only to the tissue that the aptamers **52** is in contact with.

Aptamers are nucleic acids that bind to the surface of molecules in much the same way as antibodies. One important difference between aptamers and antibodies is that aptamers can be produced by chemical synthesis whereas antibodies are produced biologically, first animals, then in culture or an expression system. Another important difference is that aptamers are very stable and not sensitive to their surrounding environment, including temperature.

In some embodiments, coating **35** may include a chemical solvent that has plaque softening properties. Ether, chloroform, benzene, and acetone are known to be lipid solvents. Furthermore, amino acids, proteins, carbohydrates, and nucleic acids are largely insoluble in these solvents. If the solvent is used in conjunction with tissue heating, the tissue treatment may require less energy over a shorter time period, lessening the chance of damage to healthy tissue. If the tissue includes calcium deposits, the same process used to deliver lipid solvents to plaque could be used to deliver calcium solvents to calcification sites. Calcium is highly soluble in a variety of organic solvents. In both cases, the solvent would be coupled to the surface of the balloon with a coating that would break down either with the application of heat or RF energy, or as the balloon is inflated.

In some embodiments, the coating may incorporate more than one drug, agent, or fluid listed herein within the coating, each having different phase change temperatures. For example, an anesthetic could be administered at a lower melting temperature prior to a specific treatment of higher temperature where there may be a nerve in the general location. In some embodiments, two coatings of differing material may be used, such as by layering. For example, a first layer may include a first drug that attaches to the target tissue and act as a receptor to a second drug in a second layer. In some embodiments the coating is non-conductive to reduce or eliminate electrical shorts between electrodes.

In some embodiments, tissue signature could be used to identify treatment regions with the use of impedance measurements. Impedance measurements utilizing the radially spaced electrodes **34** within a lumen can be used to analyze tissue. Impedance measurements between pairs of adjacent electrodes (and/or between pairs of separated electrodes), may differ when the current path passes through diseased tissue, and when it passes through healthy tissues of the luminal wall. Hence, impedance measurements between the electrodes on either side of diseased tissue may indicate a lesion, while measurements between other pairs of adjacent electrodes indicate healthy tissue. Other characterization, such as intravascular ultrasound, optical coherence tomography, or the like may be used to identify regions to be treated.

Some embodiments described herein may be used to treat atherosclerotic disease by selective drug delivery in combination with "gentle heating" utilizing the "Q10 Rule" to further enhance the fluid or drug treatment. Under the Q10 Rule, it is well known that rates of biochemical reactions usually double when temperature is increased by 10° C.

As shown in FIG. **6**, electrodes **34** are positioned circumferentially around the balloon **20**. RF energy **43** is directed to electrodes adjacent pairs of electrodes **34A** and **34C**, or **34A** and **34D**, or any combination of **34A-34D**, treating both the healthy tissue **45** and atherosclerotic material **48** within lumen **50**. This arrangement creates an energy path **43** through the tissue that delivers energy or heat ("tissue remodeling energy") in particular treatment zones or segments to the artery tissue between the electrode pairs ("remodeling zones") having a volume between the electrode pairs at a specific depth. Using different combinations of electrode pairs may reduce or eliminate gaps between the remodeling

zones by using overlapping pairs. Using electrode pairs with bipolar energy may avoid some potential issues of the monopolar approach. Diseased artery tissue **48** has a higher electrical resistivity than healthy artery tissue. By using pairs of electrodes **34A**, **34B** in a bipolar system, tissue remodeling energy will go through the healthy tissue, diseased tissue, or a combination of both healthy and diseased tissues between the electrode pairs in the remodeling zones. Any number of electrode pairs may be used in different patterns or arrays to create a number of remodeling zones. The controller may apply either constant power, constant current, or constant voltage, whichever has the most advantage.

The controller **40** may energize the electrodes with about 0.25 to 5 Watts average power for 1 to 180 seconds, or with about 4 to 45 Joules. Higher energy treatments are done at lower powers and longer durations, such as 0.5 Watts for 90 seconds or 0.25 Watts for 180 seconds. Most treatments in the 2 to 4 Watt range are performed in 1 to 4 seconds. Using a wider electrode spacing, it would be appropriate to scale up the power and duration of the treatment, in which case the average power could be higher than 5 Watts, and the total energy could exceed 45 Joules. Likewise, using a shorter or smaller electrode pair would require scaling the average power down, and the total energy could be less than 4 Joules. The power and duration are calibrated to be less than enough to cause severe damage, and particularly less than enough to ablate diseased tissue **48** within a blood vessel.

In some embodiments the delivery of the drug and gentle heat may be accompanied by balloon angioplasty using gentle dilation to remodel the artery with dilation pressures which are at or significantly lower than standard, unheated angioplasty dilation pressures. Where balloon inflation pressures of 10-16 atmospheres may, for example, be appropriate for standard angioplasty dilation of a particular lesion, modified dilation treatments combined with appropriate electrical potentials (through flexible circuit electrodes on the balloon, electrodes deposited directly on the balloon structure, or the like) described herein may employ from 10-16 atmospheres or may be effected with pressures of 6 atmospheres or less, and possibly as low as 1 to 2 atmospheres. Such moderate dilations pressures may (or may not) be combined with one or more aspects of the tissue characterization, tuned energy, eccentric treatments, and other treatment aspects described herein for treatment of diseases of the peripheral vasculature. Covalently Bound BioMolecules

Current endovascular therapies for preventing or permanently removing hyperplastic neointima are not completely efficacious. While removal of such tissue is achieved by multiple such therapies, regrowth of the tissue is a frequent occurrence, leading to restenosis and dysfunctional blood flow. Drug-eluting stents are able to inhibit the frequency of restenosis, but fall short of completely restoring vascular function, owing to the presence of a persistent implant; the stent.

More recently, drug clotting balloons have shown an even greater reduction in the frequency of restenosis than drug eluting stents and are removed after treatment, however, high pressure inflation is required to optimally deliver the anti-proliferation/anti-inflammatory biomolecules. The molecules may function to prevent restenosis by preventing inflammatory cell influx (chemo taxis), cell proliferation. The molecules may also function to stabilize the IEL matrix by providing structural support, thus "setting" the lumen diameter.

FIGS. 9A and 9B show another embodiment of a catheter system **200** for drug delivery to a body tissue **248**. The system **200** is similar to system **10** above, except the use of biomolecules **235** coupled to the balloon **20** instead of a coating. The

biomolecules **235** include a thermally releasable active portion **235a** and an inert portion **235b** coupled by covalent bond to a balloon **20** surface. The active portion or molecule **235b** is capable of treating the desired tissue **248**, which may be enhanced with temperature or pressure. The inert portion **235a** of the biomolecule stays on the balloon. The embodiment described herein utilizes a radiofrequency endovascular balloon catheter that, upon low pressure inflation and energy delivery from the balloon to the atherosclerotic lesion, hyperthermally releases the active portion of the biomolecule that is covalently bound to the balloon, thus, delivering the active portion of the molecule to the targeted tissue. The energy may also include ultrasound emitting energy. The active molecule **235b** functions to prevent production of hyperplastic tissue by any means, including, but not limited to, cytostasis (prevention of mitosis), receptor maturation (i.e., those receptors at/on cells on the targeted tissue that are adhesive to/for a chemotactic to/for infiltrating cells that promote hyperplastic tissue formation.

The molecule's bioactive portion **235b** is released from the intact biomolecule **235** by delivery of energy (such as from electrodes **34**) that induces a local hyperthermia environment. The molecule is stable under the hyperthermia conditions. The molecule can prevent one or all of the following functions:

- cell proliferation:
- cell function:
- receptor-ligand binding:
- chemotaxis of inflammatory cells to the target tissue and migration of cells in the native artery strata to the diseased tissue.

The influx of the molecule **235b** into the diseased tissue **48** is facilitated and/or hastened by the energy mediated hypothermia, i.e., cleavage from the intact biomolecule, migration into the diseased tissue, and residence in the diseased tissue by virtue of increased porosity are all accelerated by the hyperthermia.

This invention uniquely delivers a bioactive molecule into diseased tissue with:

- greater speed, by hypothermal acceleration:
- more completeness, by rendering the diseased tissue more receptive/porous to the molecule: and/or
- with no inactive segments of the biomolecule, i.e., no polymer, inactive protein sequence/segment, or co-factors required for activation left at the treatment site (the inactive segments stay on the balloon).

Clinical application and uses are designed to reduce plaque, inhibit restenosis in stented or not-stented site, and may be used as an adjunctive treatment to aggressive non-implantable endovascular procedures and stent implants. Fluid Delivery Channels

FIG. 7 shows another embodiment of a catheter system **100** having fluid delivery channels for selective fluid delivery to a body tissue being disposed about a lumen. The catheter system **100** includes a balloon catheter **112** having a catheter body **114** with a proximal end **116** and a distal end **118**. Catheter body **114** is flexible and defines a catheter axis **115**, and may include one or more lumens, such as a guidewire lumen **122** and an inflation lumen **124**. Catheter **112** includes an inflatable balloon **120** adjacent distal end **118** and a housing **129** adjacent proximal end **116**. Housing **129** includes a first connector **126** in communication with guidewire lumen **122** and a second connector **128** in fluid communication with inflation lumen **124**. Inflation lumen **124** extends between balloon **120** and second connector **128**. Both first and second connectors **126**, **128** may optionally comprise a standard

connector, such as a Luer-Loc™ connector. A distal tip may include an integral tip valve to allow passage of guidewires, and the like.

Housing 129 also accommodates an electrical connector 138. Connector 138 includes a plurality of electrical connections, each electrically coupled to electrodes 134 via conductors 136. This allows electrodes 134 to be easily energized, the electrodes often being energized by a controller 140 and power source 142, such as RF energy, microwave energy, ultrasound energy, or other suitable energy sources. In one embodiment, electrical connector 138 is coupled to an RF generator via a controller 140, with controller 140 allowing energy to be selectively directed to electrodes 134 or electrode pairs. Controller 140 may include a processor or be coupled to a processor to control or record treatment.

FIG. 8A shows a cross-section of the balloon 120 and FIG. 8B is an enlarged section showing fluid delivery channels 160 through the balloon 120 coupled to electrodes 134 mounted on a surface of balloon 120. Electrodes 134 include associated conductors extending proximally from the electrodes. Electrodes 134 and fluid delivery channels 160 may be arranged in many different patterns or arrays on balloon 120. Fluid delivery channels 160 may be coupled to a fluid reservoir or lumen 162 holding the fluid 152. In some embodiments, the inflation medium may contain the fluid to be delivered. In some embodiments, the channels 160 thru balloon 120 may be filled with wax-like material 164 that can be expelled thermally in order to open the channel (or any other material that can be expelled). In other embodiments, electrodes 134 may open and close a flap to release the fluid.

The delivery channels 160 may protrude from the balloon surface such that they are capable of penetrating the body tissue of the lumen. In some embodiments, the electrodes may penetrate the body tissue.

The catheter system 100 may also include a tissue analyzer configured to characterize the body tissue. In some embodiments, electrodes 134 may be sensing electrodes, as discussed above, that could help characterize the tissue to identify regions to be treated or not using electrical impedance tomography. Other characterization, such as intravascular ultrasound, optical coherence tomography, or the like may be used to identify regions to be treated. Electrodes 134 may be energized in response to the characterized body tissue.

Some embodiments described herein may be used to treat atherosclerotic disease by selective fluid delivery in combination with “gentle heating” to further enhance the fluid delivery or treatment, as discussed above.

Electrodes 134 may be selectively energized to open or close fluid delivery channels 160 to treat tissue. One method includes opening the fluid delivery channels 160 by selectively heating the electrodes (by Joule heating or other means, including inducing a heightened temperature in the adjacent region, whereby heat transfer could heat the electrode(s)), such that a material 164, that would otherwise block the channel, is phase changed from solid to liquid. Another possible method may include the use of MEMS (micro-electromechanical-systems) to open and/or close channels 160 selectively.

In some embodiments, the fluid delivery channels may be vias through the electrodes (perfused electrodes). The vias or small holes may be used to deliver a fluid to the artery tissue proximate the electrode. The holes may be less than 1 μm in diameter and may be made with a laser or ion beam. The holes may be made in the electrodes and balloon. In one example, electrode pads on a flexible circuit are designed with vias that are plated. The flexible circuit is mounted on a balloon and a laser or ion beam is used to create the holes in the flexible

substrate and balloon. There may be several holes in the flexible/balloon for every electrode pad. The balloon may then be perfused with standard perfusion balloon equipment or specialized equipment. This perfusion approach may also provide additional advantages beyond fluid delivery, such as eliminating sticking, carry away heat or regulate the impedance of the load.

In some embodiments, a porous balloon may be used having fluid delivery channels on a micro-level, allowing select molecules through with the addition of heat. The porous balloon may have an inner layer, a porous outer layer or membrane, drug or fluid molecules positioned between the layers (i.e., a reservoir) and electrodes coupled to the outer layer. At low pressures, the molecules stay within the reservoir. As heat is applied, the molecules may go through the porous layer, which may be done in different ways. For example, as the heat is applied, the drug molecules may become excited, providing enough force to go through the porous outer layer. In another example, as heat is applied to the balloon, the pores expand, allowing the drug molecules to go through the porous outer layer. The molecules may also pass through the porous outer layer or membrane by osmotic pressure along with the heat.

In some embodiments, the treatments may include a drug, and/or thermal, and/or small or large molecules injection, and/or RF, and/or balloon dilatation, and/or hyperthermia.

While the devices, systems, and methods disclosed herein discuss a balloon as the radially expandable structure, other expandable structures may also be used, such as described in U.S. patent application Ser. No. 11/975,651, the full disclosure of which is incorporated herein by reference.

Thermally Excited Osmolarity

In some embodiments, a porous balloon may be used having fluid delivery channels on a micro-level in a membrane, allowing molecules through with the addition of pressure and heat. The concept delivers a fluid or drug to a specific site by passing it through the membrane, much like reverse osmosis. In reverse osmosis, a pressure is used to drive a liquid, such as water, through a membrane with passages so small that only the appropriate molecules can pass through. In this embodiment, the membrane barrier retains a drug, like paclitaxel. At low pressures, the drug molecules are not able to pass through the membrane. To release the drug through the membrane, pressure is applied to the drug molecules using a balloon the release of the drug is accelerated by applying energy locally by an electrode pair or monopolar electrode.

FIG. 10 shows one embodiment of a catheter system, similar to catheter system 10, having a balloon 300 with a non-porous inner balloon 305 (to provide pressure), a porous outer layer, membrane or sleeve 310, a drug or fluid 315 positioned between inner balloon 305 and membrane 310 (i.e., a reservoir), and electrodes 320 coupled to the membrane 310. Electrodes 320 may be similar to the electrodes describe above.

In use, the balloon is placed at the desired tissue site and the balloon is inflated to a suitable pressure, such as 4-6 ATM. When the electrodes are energized, the heat energy causes the membrane pores to open and the drug molecule to excite and make their way through the pores to the tissue.

The devices, systems, and methods disclosed herein may be used to selectively deliver fluid in any artery, for example, the femoral, popliteal, coronary and/or carotid arteries. While the disclosure focuses on the use of the technology in the vasculature, the technology would also be useful for any luminal obstruction. Other anatomical structures in which the present invention may be used are the esophagus, the oral cavity, the nasopharyngeal cavity, the auditory tube and tympanic cavity, the sinus of the brain, the arterial system, the

venous system, the heart, the larynx, the trachea, the bronchus, the stomach, the duodenum, the ileum, the colon, the rectum, the bladder, the ureter, the ejaculatory duct, the vas deferens, the urethra, the uterine cavity, the vaginal canal, and the cervical canal.

The devices, systems, and method disclosed herein may employ one or more of a wide variety of mechanisms to facilitate, promote, and/or enhance transport of at least one drug from a fluid, gel, or solid of a catheter (or other delivery structure) toward, to and/or into a desired treatment site or tissue. Exemplary thermally-mediated drug transport mechanisms which may be employed are described above. Additional mechanisms may also be used including electrically mediated drug transport mechanisms, optionally including mechanisms such as electroporation, iontophoresis, and the like. Electroporation may allow targeting drug molecules intracellularly via creating passages in the cell membrane. Electroporation can significantly increase the electrical conductivity and permeability of the cell plasma membrane by application of an external electrical field, optionally by application of an electroporation voltage (which may involve a series of electroporation potentials) using one or more electrodes of the balloon catheters described herein. Iontophoresis may be employed by applying a relatively small electric potential so as to deliver a medicine or other chemical through the luminal surface, with the electrical potential again optionally being applied using one or more electrodes of the balloon catheters described hereinabove. As another example, anti-inflammatory molecules could be delivered via iontophoretic membranes to atherosclerotic lesions. Small molecule inhibitors of inflammation, thrombogenesis, and thrombosis can be delivered to atherosclerotic lesions via iontophoretic methods using devices and systems described herein to slow or prevent progression of atherosclerosis and thrombus formation. Examples of suitable inflammatory and/or thrombogenic tissue targets in the artery may include platelet cell adhesion factor (PECAM), Tissue Factor (TF), matrix metalloproteinases (MMP), and/or the like. Examples of a small molecule anti-inflammatory/anti-thrombosis therapeutics that would be amenable to delivery via iontophoresis may include heparin, heparin sulfate, and/or the like. Advantageously, suitable potentials may be applied in either a bipolar arrangement (between electrodes of the balloon catheter) or in a monopolar mode. Suitable potentials may be applied by commercially available iontophoresis or electroporation systems, or specialized potential generators may be employed. These drug transport mechanisms can optionally be combined, for example, with a thermal mechanism used (for example, by energizing electrodes so as to heat a coating, and optionally to facilitate release of a drug and thermally enhance movement of the drug into a target tissue), followed with an electrically mediated drug transport mechanism (optionally by energizing the same electrodes or different electrodes of the balloon with a suitable potential).

While the exemplary embodiments have been described in some detail, by way of example and for clarity of understanding, those of skill in the art will recognize that a variety of modification, adaptations, and changes may be employed. Hence, the scope of the present invention should be limited solely by the appending claims.

What is claimed is:

1. A medical device, comprising:
 - a catheter shaft having a distal region;
 - an expandable member coupled to the distal region;
 - a coating disposed along the expandable member, the coating including a releasable drug;

a plurality of electrodes coupled to the expandable member;

wherein the plurality of electrodes includes one or more pairs of bipolar electrodes; and

wherein the electrodes are configured to induce a phase change in the coating and release the releasable drug from the coating.

2. The medical device of claim 1, wherein the expandable member includes a balloon.

3. The medical device of claim 2, wherein the electrodes are mounted to an outer surface of the balloon.

4. The medical device of claim 2, wherein the balloon is configured to be fully inflated with a pressure of 6 atmospheres or less.

5. The medical device of claim 2, wherein the balloon is configured to be fully inflated with a pressure of 1 to 2 atmospheres.

6. The medical device of claim 1, further comprising a generator coupled to the catheter shaft for selectively energizing the plurality of electrodes.

7. The medical device of claim 6, wherein the generator is configured to energize the electrodes for 1 to 180 seconds.

8. The medical device of claim 6, wherein the generator is configured to energize the electrodes with 0.25 to 5 Watts average power.

9. The medical device of claim 6, wherein the generator includes an RF energy source.

10. The medical device of claim 1, wherein at least some of the plurality of electrodes are configured to sense impedance.

11. The medical device of claim 1, wherein at least some of the plurality of electrodes are configured to characterize target tissue based on sensed impedance.

12. The medical device of claim 1, wherein the coating has coating melting temperature above 37° Celsius.

13. The medical device of claim 1, wherein energizing the electrodes liquefies at least a portion of the coating.

14. A medical device, comprising:

a catheter shaft having a distal region;

a balloon coupled to the distal region;

a coating disposed on the balloon, the coating including a releasable drug;

one or more pairs of bipolar electrodes coupled to the balloon;

wherein the electrodes are configured to induce a phase change in the coating and release the releasable drug from the coating, wherein the phase change of the coating from a solid to a liquid releases the drug; and

a generator coupled to the catheter shaft, the generator being configured to selectively energize the electrodes.

15. The medical device of claim 14, wherein the generator includes an RF energy source.

16. The medical device of claim 14, wherein at least some of the one or more pairs of bipolar electrodes are configured to sense impedance and characterize target tissue based on sensed impedance.

17. The medical device of claim 14, wherein the coating has coating melting temperature above 37° Celsius.

18. The medical device of claim 14, wherein energizing the electrodes liquefies at least a portion of the coating.

19. A medical device, comprising:

a catheter shaft having a distal region;

a balloon coupled to the distal region;

a thermally changeable coating disposed on the balloon, the coating including a releasable drug;

wherein the thermally changeable coating has a coating melting temperature above 37° Celsius;

one or more pairs of bipolar electrodes coupled to the balloon;
wherein the electrodes are configured to heat the coating above the coating melting temperature so as to at least partially liquefy the coating and release the releasable drug from the coating; and
a generator coupled to the catheter shaft, the generator being configured to selectively energize the electrodes.

* * * * *

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当前申请(专利权)人(译)	VESSIX血管, INC.		
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摘要(译)

公开了用于通过涂层或流体输送通道在内腔中选择性药物或流体输送的方法和系统。一种系统包括细长导管，该细长导管具有近端和远端，其间具有轴线，该导管在远端附近具有可径向扩张的球囊，并且靠近球囊的能量输送部分用于传递能量，具有可释放的热可变涂层当可膨胀球囊膨胀时，热可变涂层被定向成被推动抵靠身体组织，并且可操作地连接到能量输送部分的能量源被配置成激励能量输送部分以加热和液化热可变涂层。将药物释放到身体组织。

