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(54) **TISSUE DIAGNOSIS AND TREATMENT
USING MINI-ELECTRODES**

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2018/1497; A61B 2018/00892;

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,773,401 A 11/1973 Douklias et al.

4,466,443 A 8/1984 Utsugi

(Continued)

FOREIGN PATENT DOCUMENTS

CA 2682055 A1 10/2008

CA 2847846 A1 3/2013

(Continued)

OTHER PUBLICATIONS

Extended European Search Report issued in EP Application 16182627.
6, dated Nov. 8, 2016, 5 pages.

(Continued)

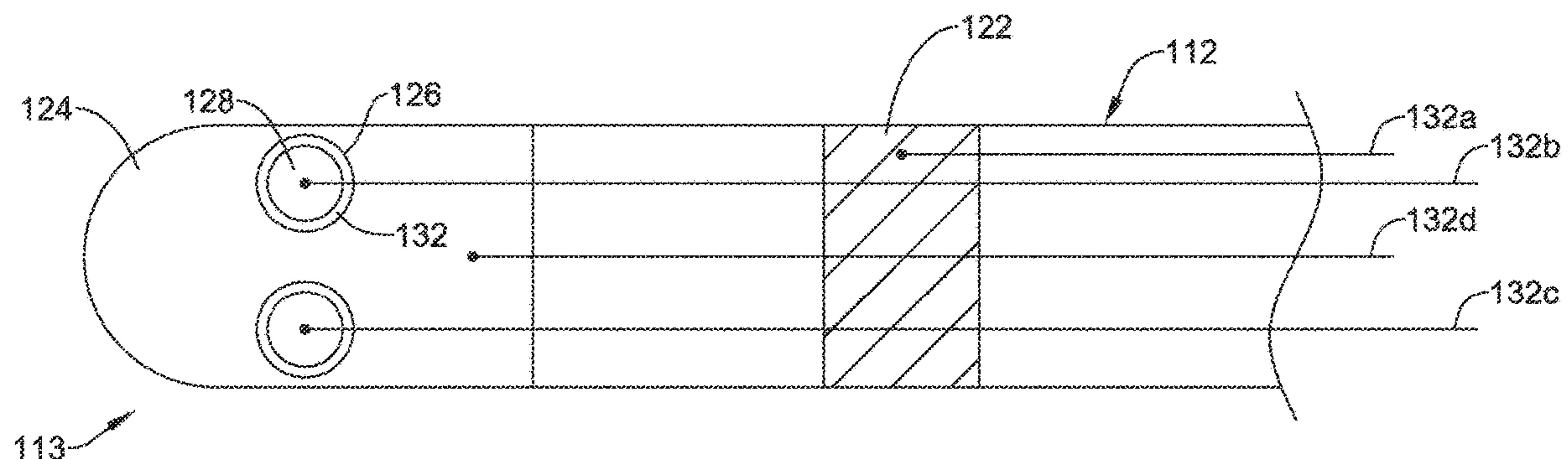
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(57) **ABSTRACT**

Medical devices and methods for making and using medical devices are disclosed. An example electrophysiology medical device may include a catheter shaft including a distal end portion and a sensing assembly having three or more terminals. The sensing assembly includes one or more current-carrying electrodes and one or more sensing electrodes. The one or more current-carrying electrodes, the one or more sensing electrodes, or both includes a mini-electrode. The mini-electrode is disposed on one of the other electrodes. The medical device may also include a controller coupled to the sensing assembly.

19 Claims, 10 Drawing Sheets



| | | | | | |
|--|--|---------------------------------------|--------------|-------------|-----------------------|
| (51) | Int. Cl. | | 5,735,846 A | 4/1998 | Panescu et al. |
| | <i>A61B 5/042</i> | (2006.01) | 5,762,067 A | 6/1998 | Dunham et al. |
| | <i>A61B 5/00</i> | (2006.01) | 5,788,636 A | 8/1998 | Curley |
| | <i>A61B 18/00</i> | (2006.01) | 5,792,064 A | 8/1998 | Panescu et al. |
| | <i>A61B 90/00</i> | (2016.01) | 5,800,482 A | 9/1998 | Pomeranz et al. |
| (52) | U.S. Cl. | | 5,820,568 A | 10/1998 | Willis |
| | CPC ... <i>A61B 5/6852</i> (2013.01); <i>A61B 2018/00351</i> (2013.01); <i>A61B 2018/00357</i> (2013.01); <i>A61B 2018/00577</i> (2013.01); <i>A61B 2018/00642</i> (2013.01); <i>A61B 2018/00827</i> (2013.01); <i>A61B 2018/00839</i> (2013.01); <i>A61B 2018/00875</i> (2013.01); <i>A61B 2018/00892</i> (2013.01); <i>A61B 2018/1407</i> (2013.01); <i>A61B 2018/1467</i> (2013.01); <i>A61B 2018/1497</i> (2013.01); <i>A61B 2090/065</i> (2016.02); <i>A61B 2562/0257</i> (2013.01) | | 5,830,213 A | 11/1998 | Panescu et al. |
| | | | 5,833,621 A | 11/1998 | Panescu et al. |
| | | | 5,836,990 A | 11/1998 | Li |
| | | | 5,868,735 A | 2/1999 | Lafontaine |
| | | | 5,871,483 A | 2/1999 | Jackson et al. |
| | | | 5,871,526 A | 2/1999 | Gibbs et al. |
| | | | 5,876,336 A | 3/1999 | Swanson et al. |
| | | | 5,885,278 A | 3/1999 | Fleischman |
| | | | 5,913,856 A | 6/1999 | Chia et al. |
| | | | 5,916,213 A | 6/1999 | Haissaguerre et al. |
| | | | 5,957,850 A | 9/1999 | Marian et al. |
| | | | 6,004,269 A | 12/1999 | Crowley et al. |
| | | | 6,027,500 A | 2/2000 | Buckles et al. |
| | | | 6,050,267 A | 4/2000 | Nardella et al. |
| | | | 6,050,994 A | 4/2000 | Sherman |
| | | | 6,059,778 A | 5/2000 | Sherman |
| | | | 6,063,078 A | 5/2000 | Wittkamp |
| | | | 6,064,905 A | 5/2000 | Webster, Jr. et al. |
| | (58) | Field of Classification Search | | 6,068,629 A | 5/2000 |
| CPC <i>A61B 2018/00875</i> ; <i>A61B 2018/00827</i> ; <i>A61B 2018/00351</i> ; <i>A61B 2018/00642</i> ; <i>A61B 2018/00357</i> ; <i>A61B 2018/00577</i> ; <i>A61B 2018/00839</i> ; <i>A61B 2018/1467</i> | | | 6,070,094 A | 5/2000 | Swanson et al. |
| See application file for complete search history. | | | 6,071,281 A | 6/2000 | Burnside et al. |
| | | | 6,083,170 A | 7/2000 | Ben-Haim |
| | | | 6,083,222 A | 7/2000 | Klein et al. |
| | | | 6,099,524 A | 8/2000 | Lipson et al. |
| | | | 6,101,409 A | 8/2000 | Swanson et al. |
| | | | 6,116,027 A | 9/2000 | Smith et al. |
| | | | 6,120,476 A | 9/2000 | Fung et al. |
| | | | 6,165,123 A | 12/2000 | Thompson |
| | | | 6,171,305 B1 | 1/2001 | Sherman |
| | | | 6,200,314 B1 | 3/2001 | Sherman |
| | | | 6,206,831 B1 | 3/2001 | Suorsa et al. |
| | | | 6,210,337 B1 | 4/2001 | Dunham et al. |
| | | | 6,216,027 B1 | 4/2001 | Willis et al. |
| (56) | References Cited | | 6,224,557 B1 | 5/2001 | Ziel et al. |
| | U.S. PATENT DOCUMENTS | | 6,233,491 B1 | 5/2001 | Kordis et al. |
| | | | 6,241,754 B1 | 6/2001 | Swanson et al. |
| | | | 6,270,493 B1 | 8/2001 | Lalonde et al. |
| | | | 6,290,697 B1 | 9/2001 | Tu et al. |
| | | | 6,352,534 B1 | 3/2002 | Paddock et al. |
| | | | 6,395,325 B1 | 5/2002 | Hedge et al. |
| | | | 6,400,981 B1 | 6/2002 | Govari |
| | | | 6,423,002 B1 | 7/2002 | Hossack |
| | | | 6,475,213 B1 | 11/2002 | Whayne et al. |
| | | | 6,488,678 B2 | 12/2002 | Sherman |
| | | | 6,491,710 B2 | 12/2002 | Satake |
| | | | 6,500,174 B1 | 12/2002 | Maguire et al. |
| | | | 6,508,767 B2 | 1/2003 | Burns et al. |
| | | | 6,508,769 B2 | 1/2003 | Bonnefous |
| | | | 6,508,803 B1 | 1/2003 | Horikawa et al. |
| | | | 6,516,667 B1 | 2/2003 | Broad et al. |
| | | | 6,517,533 B1 | 2/2003 | Swaminathan |
| | | | 6,517,534 B1 | 2/2003 | McGovern et al. |
| | | | 6,537,271 B1 | 3/2003 | Murray et al. |
| | | | 6,544,175 B1 | 4/2003 | Newman |
| | | | 6,546,270 B1 | 4/2003 | Goldin et al. |
| | | | 6,547,788 B1 | 4/2003 | Maguire et al. |
| | | | 6,569,160 B1 | 5/2003 | Goldin et al. |
| | | | 6,572,547 B2 | 6/2003 | Miller et al. |
| | | | 6,575,966 B2 | 6/2003 | Lane et al. |
| | | | 6,575,969 B1 | 6/2003 | Rittman et al. |
| | | | 6,579,278 B1 | 6/2003 | Bencini |
| | | | 6,582,372 B2 | 6/2003 | Poland |
| | | | 6,584,345 B2 | 6/2003 | Govari |
| | | | 6,589,182 B1 | 7/2003 | Loftman et al. |
| | | | 6,592,525 B2 | 7/2003 | Miller et al. |
| | | | 6,602,242 B1 | 8/2003 | Fung et al. |
| | | | 6,620,103 B1 | 9/2003 | Bruce et al. |
| | | | 6,632,179 B2 | 10/2003 | Wilson et al. |
| | | | 6,638,222 B2 | 10/2003 | Chandrasekaran et al. |
| | | | 6,640,120 B1 | 10/2003 | Swanson et al. |
| | | | 6,647,281 B2 | 11/2003 | Morency |
| | | | 6,656,174 B1 | 12/2003 | Hegde et al. |
| | | | 6,658,279 B2 | 12/2003 | Swanson et al. |

(56)

References Cited

U.S. PATENT DOCUMENTS

| | | | | | |
|--------------|---------|--------------------|-----------------|---------|---------------------|
| 6,663,573 B2 | 12/2003 | Goldin | 7,736,362 B2 | 6/2010 | Eberl et al. |
| 6,666,862 B2 | 12/2003 | Jain et al. | 7,740,629 B2 | 6/2010 | Anderson et al. |
| 6,673,067 B1 | 1/2004 | Peyman | 7,758,508 B1 | 7/2010 | Thiele et al. |
| 6,676,606 B2 | 1/2004 | Simpson et al. | 7,766,833 B2 | 8/2010 | Lee et al. |
| 6,692,441 B1 | 2/2004 | Poland et al. | 7,776,033 B2 | 8/2010 | Swanson |
| 6,705,992 B2 | 3/2004 | Gatzke | 7,785,324 B2 | 8/2010 | Eberl |
| 6,709,396 B2 | 3/2004 | Flesch et al. | 7,794,398 B2 | 9/2010 | Salgo |
| 6,711,429 B1 | 3/2004 | Gilboa et al. | 7,796,789 B2 | 9/2010 | Salgo et al. |
| 6,719,756 B1 | 4/2004 | Muntermann | 7,799,025 B2 | 9/2010 | Wellman |
| 6,723,094 B1 | 4/2004 | Desinger | 7,815,572 B2 | 10/2010 | Loupas |
| 6,735,465 B2 | 5/2004 | Panescu | 7,819,863 B2 | 10/2010 | Eggers et al. |
| 6,736,814 B2 | 5/2004 | Manna et al. | 7,837,624 B1 | 11/2010 | Hossack et al. |
| 6,743,174 B2 | 6/2004 | Ng et al. | 7,859,170 B2 | 12/2010 | Knowles et al. |
| 6,773,402 B2 | 8/2004 | Govari et al. | 7,862,561 B2 | 1/2011 | Swanson et al. |
| 6,776,758 B2 | 8/2004 | Peszynski et al. | 7,862,562 B2 | 1/2011 | Eberl |
| 6,796,979 B2 | 9/2004 | Lentz | 7,879,029 B2 | 2/2011 | Jimenez |
| 6,796,980 B2 | 9/2004 | Hall | 7,892,228 B2 | 2/2011 | Landis et al. |
| 6,804,545 B2 | 10/2004 | Fuimaono et al. | 7,894,871 B2 | 2/2011 | Wittkamp et al. |
| 6,811,550 B2 | 11/2004 | Holland et al. | 7,918,850 B2 | 4/2011 | Govari et al. |
| 6,824,517 B2 | 11/2004 | Salgo et al. | 7,957,817 B1 | 6/2011 | Gillespie et al. |
| 6,837,884 B2 | 1/2005 | Woloszko | 7,996,085 B2 | 8/2011 | Levin |
| 6,845,257 B2 | 1/2005 | Fuimaono et al. | 8,016,822 B2 | 9/2011 | Swanson |
| 6,845,264 B1 | 1/2005 | Skladnev et al. | 8,048,028 B2 | 11/2011 | Horn et al. |
| 6,917,834 B2 | 7/2005 | Koblish et al. | 8,103,327 B2 | 1/2012 | Harlev et al. |
| 6,922,579 B2 | 7/2005 | Taimisto et al. | 8,128,617 B2 | 3/2012 | Bencini et al. |
| 6,923,808 B2 | 8/2005 | Taimisto | 8,160,690 B2 | 4/2012 | Wilfley et al. |
| 6,932,811 B2 | 8/2005 | Hoooven et al. | 8,162,935 B2 | 4/2012 | Paul et al. |
| 6,945,938 B2 | 9/2005 | Grunwald | 8,265,745 B2 | 9/2012 | Hauck et al. |
| 6,950,689 B1 | 9/2005 | Willis et al. | 8,267,926 B2 | 9/2012 | Paul et al. |
| 6,952,615 B2 | 10/2005 | Satake | 8,290,578 B2 | 10/2012 | Schneider |
| 6,958,040 B2 | 10/2005 | Oliver et al. | 8,317,783 B2 | 11/2012 | Cao et al. |
| 7,001,383 B2 | 2/2006 | Keidar | 8,369,922 B2 | 2/2013 | Paul et al. |
| 7,037,264 B2 | 5/2006 | Poland | 8,400,164 B2 | 3/2013 | Osadchy et al. |
| 7,047,068 B2 | 5/2006 | Haissaguerre | 8,403,925 B2 | 3/2013 | Miller et al. |
| 7,097,643 B2 | 8/2006 | Cornelius et al. | 8,406,866 B2 | 3/2013 | Deno et al. |
| 7,099,711 B2 | 8/2006 | Fuimaono et al. | 8,414,579 B2 | 4/2013 | Kim et al. |
| 7,105,122 B2 | 9/2006 | Karason | 8,449,535 B2 | 5/2013 | Deno et al. |
| 7,112,198 B2 | 9/2006 | Satake | 8,454,538 B2 | 6/2013 | Wittkamp et al. |
| 7,115,122 B1 | 10/2006 | Swanson et al. | 8,454,589 B2 | 6/2013 | Deno et al. |
| 7,123,951 B2 | 10/2006 | Fuimaono et al. | 8,489,184 B2 | 7/2013 | Wilfley et al. |
| 7,131,947 B2 | 11/2006 | Demers | 8,579,889 B2 | 11/2013 | Bencini |
| 7,166,075 B2 | 1/2007 | Varghese et al. | 8,583,215 B2 | 11/2013 | Lichtenstein |
| 7,181,262 B2 | 2/2007 | Fuimaono et al. | 8,603,084 B2 | 12/2013 | Fish et al. |
| 7,220,233 B2 | 5/2007 | Nita et al. | 8,603,085 B2 | 12/2013 | Jimenez |
| 7,232,433 B1 | 6/2007 | Schlesinger et al. | 8,644,950 B2 | 2/2014 | Hauck |
| 7,247,155 B2 | 7/2007 | Hoey et al. | 8,657,814 B2 | 2/2014 | Werneth et al. |
| 7,270,634 B2 | 9/2007 | Scampini et al. | 8,672,936 B2 | 3/2014 | Thao et al. |
| 7,288,088 B2 | 10/2007 | Swanson | 8,679,109 B2 | 3/2014 | Paul et al. |
| 7,291,142 B2 | 11/2007 | Eberl et al. | 8,728,077 B2 | 5/2014 | Paul et al. |
| 7,306,561 B2 | 12/2007 | Sathyanarayana | 8,740,900 B2 | 6/2014 | Kim et al. |
| 7,335,052 B2 | 2/2008 | D'Sa | 8,755,860 B2 | 6/2014 | Paul et al. |
| 7,347,820 B2 | 3/2008 | Bonnefous | 8,771,343 B2 | 7/2014 | Weber et al. |
| 7,347,821 B2 | 3/2008 | Dkyba et al. | 8,876,817 B2 | 11/2014 | Avitall et al. |
| 7,347,857 B2 | 3/2008 | Anderson et al. | 8,894,643 B2 | 11/2014 | Watson et al. |
| 7,361,144 B2 | 4/2008 | Levrier et al. | 8,906,011 B2 | 12/2014 | Gelbart et al. |
| 7,422,591 B2 | 9/2008 | Phan | 8,945,015 B2 | 2/2015 | Rankin et al. |
| 7,438,714 B2 | 10/2008 | Phan | 8,998,890 B2 | 4/2015 | Paul et al. |
| 7,455,669 B2 | 11/2008 | Swanson | 9,089,340 B2 | 7/2015 | Hastings et al. |
| 7,488,289 B2 | 2/2009 | Suorsa et al. | 9,125,565 B2 | 9/2015 | Hauck |
| 7,507,205 B2 | 3/2009 | Borovsky et al. | 9,125,668 B2 | 9/2015 | Subramaniam et al. |
| 7,519,410 B2 | 4/2009 | Taimisto et al. | 9,168,004 B2 | 10/2015 | Gliner et al. |
| 7,529,393 B2 | 5/2009 | Peszynski et al. | 9,173,586 B2 | 11/2015 | Deno et al. |
| 7,534,207 B2 | 5/2009 | Shehada et al. | 9,211,156 B2 | 12/2015 | Kim et al. |
| 7,544,164 B2 | 6/2009 | Knowles et al. | 9,241,687 B2 | 1/2016 | McGee |
| 7,549,988 B2 | 6/2009 | Eberl et al. | 9,241,761 B2 | 1/2016 | Rankin et al. |
| 7,569,052 B2 | 8/2009 | Phan et al. | 9,254,163 B2 | 2/2016 | Paul et al. |
| 7,578,791 B2 | 8/2009 | Rafter | 9,265,434 B2 | 2/2016 | Merschon et al. |
| 7,582,083 B2 | 9/2009 | Swanson | 9,271,782 B2 | 3/2016 | Paul et al. |
| 7,585,310 B2 | 9/2009 | Phan et al. | 9,283,026 B2 | 3/2016 | Paul et al. |
| 7,610,073 B2 | 10/2009 | Fuimaono et al. | 9,370,329 B2 | 6/2016 | Tun et al. |
| 7,648,462 B2 | 1/2010 | Jenkins et al. | 9,393,072 B2 | 7/2016 | Kim et al. |
| 7,697,972 B2 | 4/2010 | Verard et al. | 9,463,064 B2 | 10/2016 | Subramaniam et al. |
| 7,704,208 B2 | 4/2010 | Thiele | 9,603,659 B2 | 3/2017 | Subramaniam et al. |
| 7,720,420 B2 | 5/2010 | Kajita | 9,757,191 B2 | 9/2017 | Avitall et al. |
| 7,727,231 B2 | 6/2010 | Swanson | 2001/0029371 A1 | 10/2001 | Kordis |
| | | | 2001/0034518 A1 | 10/2001 | Edwards et al. |
| | | | 2002/0007180 A1 | 1/2002 | Wittenberger et al. |
| | | | 2002/0087208 A1 | 7/2002 | Koblish et al. |
| | | | 2002/0165448 A1 | 11/2002 | Ben-Haim et al. |

(56)

References Cited

U.S. PATENT DOCUMENTS

| | | | | | |
|-----------------|---------|------------------|------------------|---------|-------------------------------|
| 2002/0183735 A1 | 12/2002 | Edwards et al. | 2008/0161705 A1 | 7/2008 | Podmore et al. |
| 2002/0198521 A1 | 12/2002 | Maguire | 2008/0161795 A1 | 7/2008 | Wang et al. |
| 2003/0004505 A1 | 1/2003 | Bencini et al. | 2008/0161796 A1 | 7/2008 | Cao et al. |
| 2003/0004506 A1 | 1/2003 | Messing | 2008/0195089 A1 | 8/2008 | Thiagalingam et al. |
| 2003/0013958 A1 | 1/2003 | Govari et al. | 2008/0228111 A1 | 9/2008 | Nita |
| 2003/0014095 A1 | 1/2003 | Kramer et al. | 2008/0243214 A1 | 10/2008 | Koblish |
| 2003/0088240 A1 | 5/2003 | Saadat | 2008/0275428 A1 | 11/2008 | Tegg et al. |
| 2003/0158548 A1 | 8/2003 | Phan et al. | 2008/0281322 A1 | 11/2008 | Sherman et al. |
| 2003/0158549 A1 | 8/2003 | Swanson | 2008/0287803 A1 | 11/2008 | Li et al. |
| 2003/0229286 A1 | 12/2003 | Lenker | 2008/0300454 A1 | 12/2008 | Goto |
| 2004/0006268 A1 | 1/2004 | Gilboa et al. | 2008/0312521 A1 | 12/2008 | Solomon |
| 2004/0082860 A1 | 4/2004 | Haissaguerre | 2008/0312713 A1 | 12/2008 | Wilfley et al. |
| 2004/0092806 A1 | 5/2004 | Sagon et al. | 2009/0005771 A1 | 1/2009 | Lieber et al. |
| 2004/0116793 A1 | 6/2004 | Taimisto et al. | 2009/0030312 A1 | 1/2009 | Hadjicostis |
| 2004/0147920 A1 | 7/2004 | Keidar | 2009/0048591 A1 | 2/2009 | Ibrahim et al. |
| 2004/0158238 A1 | 8/2004 | Lalonde et al. | 2009/0056344 A1 | 3/2009 | Poch |
| 2004/0162556 A1 | 8/2004 | Swanson | 2009/0062790 A1 | 3/2009 | Malchano et al. |
| 2004/0186467 A1 | 9/2004 | Swanson et al. | 2009/0062795 A1 | 3/2009 | Vakharia et al. |
| 2004/0210136 A1 | 10/2004 | Varghese et al. | 2009/0076390 A1 | 3/2009 | Lee et al. |
| 2004/0215177 A1 | 10/2004 | Swanson | 2009/0093810 A1 | 4/2009 | Subramaniam et al. |
| 2004/0215186 A1 | 10/2004 | Cornelius et al. | 2009/0093811 A1 | 4/2009 | Koblish et al. |
| 2005/0033331 A1 | 2/2005 | Burnett et al. | 2009/0099472 A1 | 4/2009 | Remmert et al. |
| 2005/0059862 A1 | 3/2005 | Phan | 2009/0131932 A1 | 5/2009 | Vakharia et al. |
| 2005/0059962 A1 | 3/2005 | Phan et al. | 2009/0163904 A1 | 6/2009 | Miller et al. |
| 2005/0059963 A1 | 3/2005 | Phan et al. | 2009/0171341 A1 | 7/2009 | Pope et al. |
| 2005/0059965 A1 | 3/2005 | Eberl et al. | 2009/0171345 A1 | 7/2009 | Miller et al. |
| 2005/0065506 A1 | 3/2005 | Phan | 2009/0177069 A1 | 7/2009 | Razavi |
| 2005/0065508 A1 | 3/2005 | Johnson et al. | 2009/0177111 A1 | 7/2009 | Miller et al. |
| 2005/0070894 A1 | 3/2005 | McClurken | 2009/0182316 A1 | 7/2009 | Bencini |
| 2005/0090817 A1 | 4/2005 | Phan | 2009/0209950 A1 | 8/2009 | Starksen |
| 2005/0119545 A1 | 6/2005 | Swanson | 2009/0216125 A1 | 8/2009 | Lenker |
| 2005/0119648 A1 | 6/2005 | Swanson | 2009/0240247 A1 | 9/2009 | Rioux et al. |
| 2005/0119649 A1 | 6/2005 | Swanson | 2009/0259274 A1 | 10/2009 | Simon et al. |
| 2005/0119653 A1 | 6/2005 | Swanson | 2009/0275827 A1 | 11/2009 | Aiken et al. |
| 2005/0119654 A1 | 6/2005 | Swanson et al. | 2009/0281541 A1 | 11/2009 | Ibrahim et al. |
| 2005/0124881 A1 | 6/2005 | Kanai et al. | 2009/0287202 A1 | 11/2009 | Ingle et al. |
| 2005/0165391 A1 | 7/2005 | Maguire et al. | 2009/0292209 A1 | 11/2009 | Hadjicostis |
| 2005/0187544 A1 | 8/2005 | Swanson et al. | 2009/0299355 A1 | 12/2009 | Bencini et al. |
| 2005/0203597 A1 | 9/2005 | Yamazaki et al. | 2009/0299360 A1 | 12/2009 | Ormsby |
| 2005/0228286 A1 | 10/2005 | Messerly et al. | 2009/0306643 A1 | 12/2009 | Pappone et al. |
| 2005/0228504 A1 | 10/2005 | Demarais | 2010/0010487 A1 | 1/2010 | Phan et al. |
| 2005/0273060 A1 | 12/2005 | Levy et al. | 2010/0030204 A1 | 2/2010 | Stein et al. |
| 2005/0288667 A1 | 12/2005 | Thompson et al. | 2010/0057072 A1 | 3/2010 | Roman et al. |
| 2006/0030919 A1 | 2/2006 | Mrva et al. | 2010/0076402 A1 | 3/2010 | Mazzone et al. |
| 2006/0089634 A1 | 4/2006 | Anderson et al. | 2010/0076426 A1 | 3/2010 | de la Rama et al. |
| 2006/0100522 A1 | 5/2006 | Yuan et al. | 2010/0094274 A1 | 4/2010 | Narayan et al. |
| 2006/0161146 A1 | 7/2006 | Cornelius et al. | 2010/0106155 A1 | 4/2010 | Anderson et al. |
| 2006/0224153 A1 | 10/2006 | Fischell et al. | 2010/0113938 A1 | 5/2010 | Park et al. |
| 2006/0247607 A1 | 11/2006 | Cornelius et al. | 2010/0114092 A1 | 5/2010 | Eisele et al. |
| 2006/0247683 A1 | 11/2006 | Danek et al. | 2010/0137944 A1* | 6/2010 | Zhu A61B 5/06 607/59 |
| 2006/0253028 A1 | 11/2006 | Lam et al. | 2010/0145221 A1 | 6/2010 | Brunnett et al. |
| 2006/0253116 A1 | 11/2006 | Avitall et al. | 2010/0152728 A1 | 6/2010 | Park et al. |
| 2007/0003811 A1 | 1/2007 | Zerfass et al. | 2010/0168557 A1 | 7/2010 | Deno et al. |
| 2007/0016054 A1 | 1/2007 | Yuan et al. | 2010/0168568 A1 | 7/2010 | Sliwa |
| 2007/0016059 A1 | 1/2007 | Morimoto et al. | 2010/0168570 A1 | 7/2010 | Sliwa et al. |
| 2007/0016228 A1 | 1/2007 | Salas | 2010/0168831 A1 | 7/2010 | Korivi et al. |
| 2007/0021744 A1 | 1/2007 | Creighton | 2010/0241117 A1 | 9/2010 | Paul et al. |
| 2007/0049925 A1 | 3/2007 | Phan et al. | 2010/0249599 A1 | 9/2010 | Hastings et al. |
| 2007/0055225 A1 | 3/2007 | Dodd, III et al. | 2010/0249603 A1 | 9/2010 | Hastings et al. |
| 2007/0073135 A1 | 3/2007 | Lee et al. | 2010/0249604 A1 | 9/2010 | Hastings et al. |
| 2007/0088345 A1 | 4/2007 | Larson et al. | 2010/0268217 A1 | 10/2010 | Habib |
| 2007/0165916 A1 | 7/2007 | Cloutier et al. | 2010/0298826 A1 | 11/2010 | Leo et al. |
| 2007/0167813 A1 | 7/2007 | Lee et al. | 2010/0331658 A1 | 12/2010 | Kim et al. |
| 2007/0181139 A1 | 8/2007 | Hauck | 2011/0028820 A1 | 2/2011 | Lau et al. |
| 2007/0225610 A1 | 9/2007 | Mickley et al. | 2011/0034915 A1 | 2/2011 | Ibrahim et al. |
| 2007/0238997 A1 | 10/2007 | Camus | 2011/0071400 A1 | 3/2011 | Hastings et al. |
| 2007/0270794 A1 | 11/2007 | Anderson et al. | 2011/0071401 A1 | 3/2011 | Hastings et al. |
| 2008/0009733 A1 | 1/2008 | Saksena | 2011/0112569 A1 | 5/2011 | Friedman et al. |
| 2008/0015568 A1 | 1/2008 | Paul et al. | 2011/0125143 A1 | 5/2011 | Gross et al. |
| 2008/0025145 A1 | 1/2008 | Peszynski et al. | 2011/0130648 A1 | 6/2011 | Beeckler et al. |
| 2008/0051841 A1 | 2/2008 | Swerdlow et al. | 2011/0137153 A1 | 6/2011 | Govari et al. |
| 2008/0058836 A1 | 3/2008 | Moll et al. | 2011/0144491 A1 | 6/2011 | Sliwa et al. |
| 2008/0086073 A1 | 4/2008 | McDaniel | 2011/0144524 A1 | 6/2011 | Fish et al. |
| 2008/0091109 A1 | 4/2008 | Abraham | 2011/0160584 A1 | 6/2011 | Paul et al. |
| 2008/0140065 A1 | 6/2008 | Rioux et al. | 2011/0237933 A1 | 9/2011 | Cohen |
| | | | 2011/0282249 A1 | 11/2011 | Tsoref et al. |
| | | | 2011/0319782 A1 | 12/2011 | Sweeney et al. |
| | | | 2012/0004547 A1 | 1/2012 | Harks et al. |

(56)

References Cited

FOREIGN PATENT DOCUMENTS

| U.S. PATENT DOCUMENTS | | | | CA | 2848053 | A1 | 3/2013 |
|-----------------------|----|---------|------------------------|----|--------------|----|---------|
| | | | | CN | 1269708 | A | 10/2000 |
| 2012/0029504 | A1 | 2/2012 | Afonso et al. | CN | 1455655 | A | 11/2003 |
| 2012/0071870 | A1 | 3/2012 | Salahieh et al. | CN | 1674836 | A | 9/2005 |
| 2012/0095347 | A1 | 4/2012 | Adam et al. | CN | 1942145 | A | 4/2007 |
| 2012/0101398 | A1 | 4/2012 | Ramanathan et al. | CN | 102271607 | A | 12/2011 |
| 2012/0116537 | A1 | 5/2012 | Liebetanz | CN | 102573986 | A | 7/2012 |
| 2012/0136346 | A1 | 5/2012 | Condie et al. | CN | 103917185 | A | 7/2014 |
| 2012/0136348 | A1 | 5/2012 | Condie et al. | CN | 103987336 | A | 8/2014 |
| 2012/0136351 | A1 | 5/2012 | Weekamp et al. | CN | 104039257 | A | 9/2014 |
| 2012/0172698 | A1 | 7/2012 | Hastings et al. | CN | 104244810 | A | 12/2014 |
| 2012/0172727 | A1 | 7/2012 | Hastings et al. | CN | 104254368 | A | 12/2014 |
| 2012/0172871 | A1 | 7/2012 | Hastings et al. | CN | 104619259 | A | 5/2015 |
| 2012/0238897 | A1 | 9/2012 | Wilfley et al. | CN | 104640513 | A | 5/2015 |
| 2012/0310064 | A1 | 12/2012 | McGee | CN | 104661609 | A | 5/2015 |
| 2012/0330304 | A1 | 12/2012 | Vegesna et al. | EP | 1343426 | B1 | 9/2003 |
| 2013/0023784 | A1 | 1/2013 | Schneider et al. | EP | 1343427 | B1 | 9/2003 |
| 2013/0023897 | A1 | 1/2013 | Wallace | EP | 1502542 | A1 | 2/2005 |
| 2013/0060245 | A1 | 3/2013 | Grunewald et al. | EP | 1547537 | A1 | 6/2005 |
| 2013/0066312 | A1 | 3/2013 | Subramaniam et al. | EP | 0985423 | B1 | 4/2006 |
| 2013/0066315 | A1 | 3/2013 | Subramaniam et al. | EP | 1717601 | A2 | 11/2006 |
| 2013/0079763 | A1 | 3/2013 | Heckel et al. | EP | 1935332 | A2 | 6/2008 |
| 2013/0165926 | A1 | 6/2013 | Mathur et al. | EP | 2755587 | A | 7/2014 |
| 2013/0172715 | A1 | 7/2013 | Just et al. | EP | 2755588 | A | 7/2014 |
| 2013/0172742 | A1 | 7/2013 | Rankin et al. | EP | 2136702 | B1 | 7/2015 |
| 2013/0172875 | A1 | 7/2013 | Govari et al. | EP | 2897545 | A1 | 7/2015 |
| 2013/0184706 | A1 | 7/2013 | Gelbart et al. | JP | H07100214 | A | 4/1995 |
| 2013/0190747 | A1 | 7/2013 | Koblish et al. | JP | 2000000242 | A | 1/2000 |
| 2013/0197363 | A1 | 8/2013 | Rankin et al. | JP | 200083918 | A | 3/2000 |
| 2013/0226169 | A1 | 8/2013 | Miller et al. | JP | 2000504242 | A | 4/2000 |
| 2013/0274582 | A1 | 10/2013 | Afonso et al. | JP | 2002528039 | A | 8/2002 |
| 2013/0331739 | A1 | 12/2013 | Gertner | JP | 2003504090 | A | 2/2003 |
| 2013/0345537 | A1 | 12/2013 | Thakur et al. | JP | 2004503335 | A | 2/2004 |
| 2014/0012251 | A1 | 1/2014 | Himmelstein et al. | JP | 2006239414 | A | 9/2006 |
| 2014/0058375 | A1 | 2/2014 | Koblish | JP | 2007163559 | A | 6/2007 |
| 2014/0066764 | A1 | 3/2014 | Subramaniam et al. | JP | 2007244857 | A | 9/2007 |
| 2014/0073893 | A1 | 3/2014 | Bencini | JP | 2009142653 | A | 12/2008 |
| 2014/0075753 | A1 | 3/2014 | Haarer et al. | JP | 2009518150 | A | 5/2009 |
| 2014/0081111 | A1 | 3/2014 | Tun et al. | JP | 2010522623 | A | 7/2010 |
| 2014/0081112 | A1 | 3/2014 | Kim et al. | JP | 2011142995 | A | 7/2011 |
| 2014/0081113 | A1 | 3/2014 | Cohen et al. | JP | 2011525842 | A | 9/2011 |
| 2014/0081262 | A1 | 3/2014 | Koblish et al. | JP | 2012531967 | A | 12/2012 |
| 2014/0100563 | A1 | 4/2014 | Govari et al. | JP | 5336465 | B2 | 11/2013 |
| 2014/0107453 | A1 | 4/2014 | Maskara et al. | JP | 2014012174 | A | 1/2014 |
| 2014/0107636 | A1 | 4/2014 | Bencini | JP | 2014531244 | A | 11/2014 |
| 2014/0128757 | A1 | 5/2014 | Banet et al. | JP | 2015501162 | A | 1/2015 |
| 2014/0142393 | A1 | 5/2014 | Piskun et al. | JP | 2015509027 | A | 3/2015 |
| 2014/0194867 | A1 | 7/2014 | Fish et al. | KR | 20100021401 | A | 2/2010 |
| 2014/0200429 | A1 | 7/2014 | Spector et al. | KR | 101490374 | B1 | 2/2015 |
| 2014/0200430 | A1 | 7/2014 | Spector | WO | WO199221278 | A1 | 12/1992 |
| 2014/0214028 | A1 | 7/2014 | Gelbart et al. | WO | WO9413358 | A1 | 6/1994 |
| 2014/0228713 | A1 | 8/2014 | Thao et al. | WO | WO9604860 | A1 | 2/1996 |
| 2014/0243917 | A1 | 8/2014 | Morley et al. | WO | WO199725916 | A1 | 7/1997 |
| 2014/0261985 | A1 | 9/2014 | Selkee | WO | WO199725917 | A1 | 7/1997 |
| 2014/0275916 | A1 | 9/2014 | Nabutovsky et al. | WO | WO199736541 | A1 | 10/1997 |
| 2014/0276052 | A1 | 9/2014 | Rankin et al. | WO | 1997045156 | A2 | 12/1997 |
| 2014/0276811 | A1 | 9/2014 | Koblish et al. | WO | WO199858681 | A2 | 12/1998 |
| 2014/0330150 | A1 | 11/2014 | Thakur et al. | WO | 1999009879 | A1 | 3/1999 |
| 2014/0336518 | A1 | 11/2014 | Shuros et al. | WO | WO1999027862 | A1 | 6/1999 |
| 2014/0358137 | A1 | 12/2014 | Hu | WO | WO9953853 | A1 | 10/1999 |
| 2014/0364715 | A1 | 12/2014 | Hauck | WO | WO2000029062 | A2 | 5/2000 |
| 2014/0364843 | A1 | 12/2014 | Paul et al. | WO | WO2000158372 | A1 | 8/2001 |
| 2014/0364848 | A1 | 12/2014 | Heimbecher et al. | WO | WO2001064145 | A1 | 9/2001 |
| 2015/0005624 | A1 | 1/2015 | Hauck et al. | WO | WO2001068173 | A2 | 9/2001 |
| 2015/0011995 | A1 | 1/2015 | Avitall et al. | WO | WO0180755 | A2 | 11/2001 |
| 2015/0018813 | A1 | 1/2015 | Gliner | WO | WO0205868 | A2 | 1/2002 |
| 2015/0133914 | A1 | 5/2015 | Koblish | WO | WO2002005868 | A2 | 1/2002 |
| 2015/0133920 | A1 | 5/2015 | Rankin et al. | WO | WO2002009599 | A2 | 2/2002 |
| 2015/0265341 | A1 | 9/2015 | Koblish | WO | WO2002019934 | A1 | 3/2002 |
| 2015/0265348 | A1 | 9/2015 | Avitall et al. | WO | WO200247569 | A1 | 6/2002 |
| 2015/0342672 | A1 | 12/2015 | Bencini et al. | WO | WO2002102234 | A2 | 12/2002 |
| 2015/0374252 | A1 | 12/2015 | Alan de la Rama et al. | WO | WO2003039338 | A2 | 5/2003 |
| 2015/0374436 | A1 | 12/2015 | Subramaniam et al. | WO | WO2007079278 | A1 | 7/2007 |
| 2016/0008065 | A1 | 1/2016 | Gliner et al. | WO | 2008003058 | A2 | 1/2008 |
| 2016/0113712 | A1 | 4/2016 | Cheung et al. | WO | WO2008046031 | A2 | 4/2008 |
| | | | | WO | WO2008118992 | A1 | 10/2008 |
| | | | | WO | WO2009032421 | A2 | 3/2009 |

(56)

References Cited

FOREIGN PATENT DOCUMENTS

| | | | |
|----|--------------|----|---------|
| WO | 2009048824 | A1 | 4/2009 |
| WO | 2009048943 | A1 | 4/2009 |
| WO | 2010054409 | A1 | 5/2010 |
| WO | WO2010056771 | A1 | 5/2010 |
| WO | 2010082146 | A1 | 7/2010 |
| WO | 2011008444 | A1 | 1/2011 |
| WO | 2011033421 | A1 | 3/2011 |
| WO | WO2011024133 | A1 | 3/2011 |
| WO | WO2011089537 | A1 | 7/2011 |
| WO | 2011101778 | A1 | 8/2011 |
| WO | WO2011095937 | A1 | 8/2011 |
| WO | 2012001595 | A1 | 1/2012 |
| WO | WO2012001595 | A1 | 1/2012 |
| WO | WO2012049621 | A1 | 4/2012 |
| WO | WO2012066430 | A1 | 5/2012 |
| WO | 2012135703 | A2 | 10/2012 |
| WO | 2012161880 | A1 | 11/2012 |
| WO | WO2012151301 | A1 | 11/2012 |
| WO | 2012166239 | A1 | 12/2012 |
| WO | 2013040201 | A2 | 3/2013 |
| WO | 2013040297 | A1 | 3/2013 |
| WO | 2014036439 | A2 | 3/2014 |
| WO | 2014058375 | A2 | 4/2014 |
| WO | 2014072879 | A2 | 5/2014 |
| WO | 2014152575 | A2 | 9/2014 |
| WO | 2015143061 | A1 | 9/2015 |
| WO | 2015183635 | A1 | 12/2015 |

OTHER PUBLICATIONS

International Preliminary Report on Patentability issued in PCT/US2015/031591, dated Dec. 6, 2016, 7 pages.

International Preliminary Report on Patentability issued in PCT/US2015/021300 dated Sep. 29, 2016, 7 pages.

International Search Report and Written Opinion issued in PCT/US2015/066874, dated Apr. 1, 2016, 11 pages.

International Preliminary Report on Patentability issued in PCT/US2015/055173, dated Apr. 27, 2017, 7 pages.

International Preliminary Report on Patentability issued in PCT/US2015/066874, dated Jun. 29, 2017, 7 pages.

Extended European Search Report issued in EP Application No. 15174537.9, dated Mar. 2, 2016, 7 pages.

Goldberg, S. Nahum et al., "Variables Affecting Proper System Grounding for Radiofrequency Ablation in an Animal Model", JVIR, vol. 11, No. 8, Sep. 2000, pp. 1069-1075.

Haverkamp, W., et. al. Coagulation of Ventricular Myocardium Using Radiofrequency Alternating Current: Bio-Physical Aspects and Experimental Findings. PACE, 12:187-195, Jan. 1989, Part II.

International Preliminary Examination Report issued in PCT/US2013/060612, completed Mar. 24, 2015, 10 pages.

International Preliminary Report on Patentability issued in PCT/US2008/058324, dated Sep. 29, 2009, 9 pages.

International Preliminary Report on Patentability issued in PCT/US2012/055155, dated Mar. 18, 2014, 11 pages.

International Preliminary Report on Patentability issued in PCT/US2012/055309, dated Mar. 18, 2014, 8 pages.

International Preliminary Report on Patentability issued in PCT/US2013/056211, completed Feb. 24, 2015, 5 pages.

International Preliminary Report on Patentability issued in PCT/US2013/058105, completed Mar. 10, 2015.

International Preliminary Report on Patentability issued in PCT/US2013/060194, dated Mar. 24, 2015, 6 pages.

International Preliminary Report on Patentability issued in PCT/US2014/027491, dated Sep. 24, 2015, 12 pages.

International Preliminary Report on Patentability issued in PCT/US2013/060183, dated Mar. 24, 2015, 6 pages.

International Search Report and Written Opinion issued in PCT/US2008/058324, dated Aug. 18, 2008, 11 pages.

International Search Report and Written Opinion issued in PCT/US2012/031819, dated Sep. 27, 2012, 16 pages.

International Search Report and Written Opinion issued in PCT/US2012/055155, dated Mar. 11, 2013, 19 pages.

International Search Report and Written Opinion issued in PCT/US2012/055309, dated Nov. 19, 2012, 13 pages.

International Search Report and Written Opinion issued in PCT/US2012/072061, dated Mar. 21, 2013, 9 pages.

International Search Report and Written Opinion issued in PCT/US2013/020503, dated Mar. 20, 2013, 10 pages.

International Search Report and Written Opinion issued in PCT/US2013/021013, dated Apr. 5, 2013, 14 pages.

International Search Report and Written Opinion issued in PCT/US2013/056211, dated Jan. 20, 2014.

International Search Report and Written Opinion issued in PCT/US2013/058105, dated Nov. 22, 2013, 16 pages.

International Search Report and Written Opinion issued in PCT/US2013/060183, dated Jan. 27, 2014, 10 pages.

International Search Report and Written Opinion issued in PCT/US2013/060194, dated Jan. 29, 2014.

International Search Report and Written Opinion issued in PCT/US2013/060194, dated Jan. 29, 2014, 10 pages.

International Search Report and Written Opinion issued in PCT/US2013/060612, dated Feb. 28, 2014, 16 pages.

International Search Report and Written Opinion issued in PCT/US2014/027491, dated Sep. 23, 2014, 17 pages.

International Search Report and Written Opinion issued in PCT/US2015/021300, dated Jun. 9, 2015, 11 pages.

International Search Report and Written Opinion issued in PCT/US2015/055173, dated Jan. 18, 2016, 11 pages.

International Search Report and Written Opinion issued in PCT/US2015/057242, dated Jan. 15, 2016, 11 pages.

International Search Report and Written Opinion issued in PCT/US2015/031591, dated Aug. 17, 2015, 11 pages.

Invitation to Pay Additional Fees and Partial International Search Report issued in PCT/US2014/027491, dated Jul. 28, 2014, 5 pages.

Machi MD, Junji, "Prevention of Dispersive Pad Skin Burns During RFA by a Simple Method", Editorial Comment, Surg Laparosc Endosc Percutan Tech, vol. 13, No. 6, Dec. 2003, pp. 372-373.

Neufeld, Gordon R. et al., "Electrical Impedance Properties of the Body and the Problem of Alternate-site Burns During Electrosurgery", Medical Instrumentation, vol. 19, No. 2, Mar.-Apr. 1985, pp. 83-87.

Partial International Search Report issued in PCT/US2012/055155, dated Dec. 20, 2012, 7 pages.

Patriciu, A. et al., "Detecting Skin Burns Induced by Surface Electrodes", published in Engineering in Medicine and Biology Society, 2001. Proceedings of the 23rd Annual International Conference of the IEEE, vol. 3, pp. 3129-3131.

Piorkowski, Christopher et al., "First in Human Validation of Impedance-Based Catheter Tip-to-Tissue Contact Assessment in the Left Atrium", Journal of Cardiovascular Electrophysiology, vol. 20, No. 12, Dec. 1, 2009, pp. 1366-1373.

Pires, L. A., et. al. Temperature-guided Radiofrequency Catheter Ablation of Closed-Chest Ventricular Myocardium with a Novel Thermistor-Tipped Catheter. American Heart Journal, 127(6):1614-1618, Jun. 1994.

Price, Adam et al., "Novel Ablation Catheter Technology that Improves Mapping Resolution and Monitoring of Lesion Maturation", The Journal of Innovations in Cardiac Rhythm Management, vol. 3, 2002, pp. 599-609.

Price, Adam et al., "P03-39 Pin Electrodes Improve Resolution: Enhanced Monitoring of Radiofrequency Lesions in the Voltage and Frequency Domains", Heart Rhythm 2010, 31st Annual Scientific Sessions, May 12-15 in Denver Colorado.

Ring, E. R., et. al. Catheter Ablation of the Ventricular Septum with Radiofrequency Energy. American Heart Journal, 117(6):1233-1240, Jun. 1989.

Steinke, Karin et al., "Dispersive Pad Site burns With Modern Radiofrequency Ablation Equipment", Surg Laparosc Endosc Permin Tech, vol. 13, No. 6, Dec. 2003, pp. 366-371.

Zachary, J.M. et al., "PO4-86 Pin Electrodes Provide Enhanced Resolution Enabling Titration of Radiofrequency Duration to Lesion Maturation", Heart Rhythm 2011, 32 Annual Scientific Sessions, May 4-7, San Francisco, CA.

(56)

References Cited

OTHER PUBLICATIONS

International Search Report and Written Opinion issued in PCT/
US2016/028006 dated Jul. 12, 2016, 12 pages.

International Preliminary Report on Patentability issued in PCT/
US2015/057242, dated May 4, 2017, 7 pages.

Partial European Search Report issued in EP Application 18177491.
0, dated Jul. 16, 2018, 11 pages.

Extended European Search Report issued in EP18177491.0, dated
Oct. 26, 2018, 10 pages.

* cited by examiner

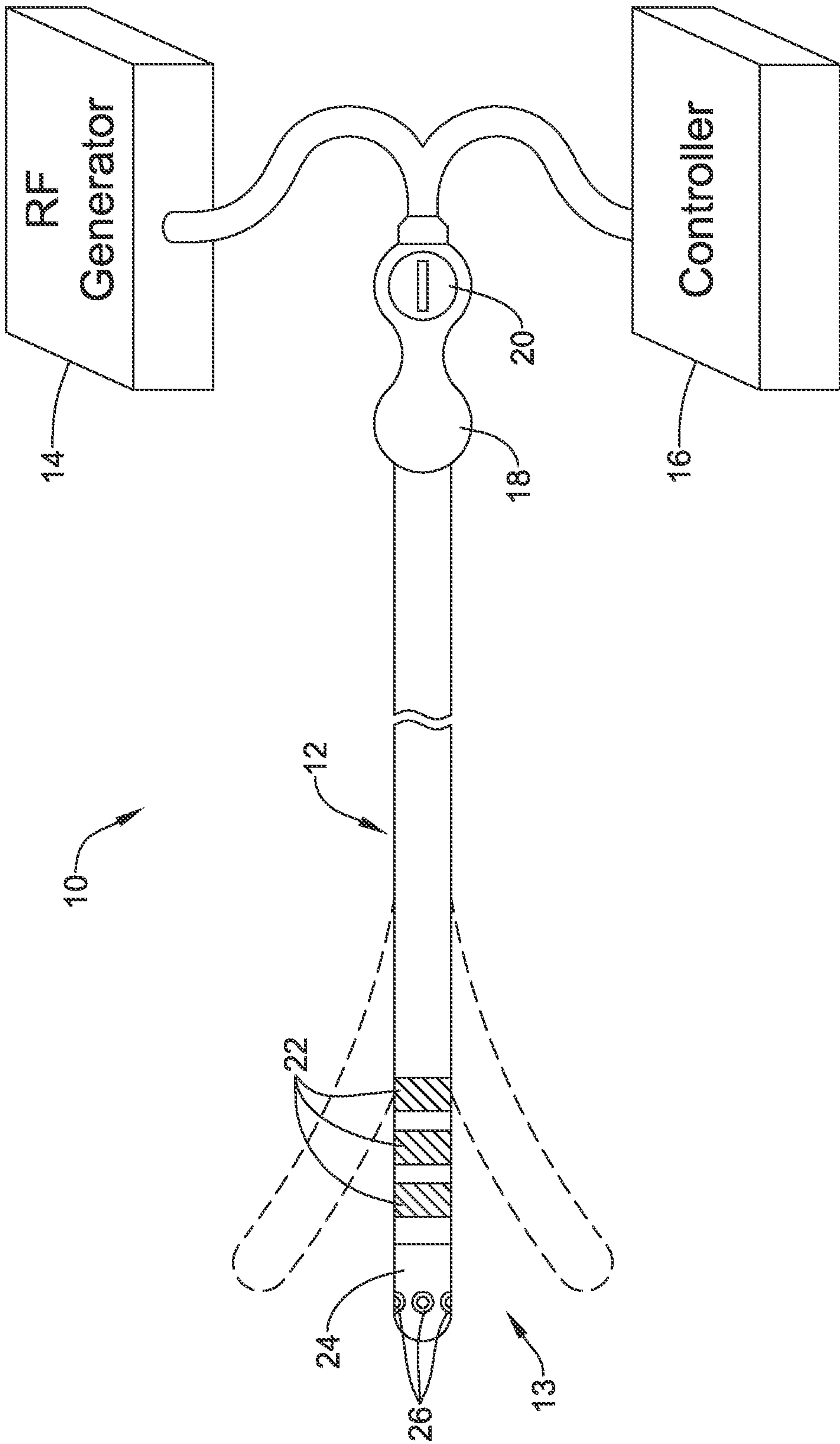


FIG. 1

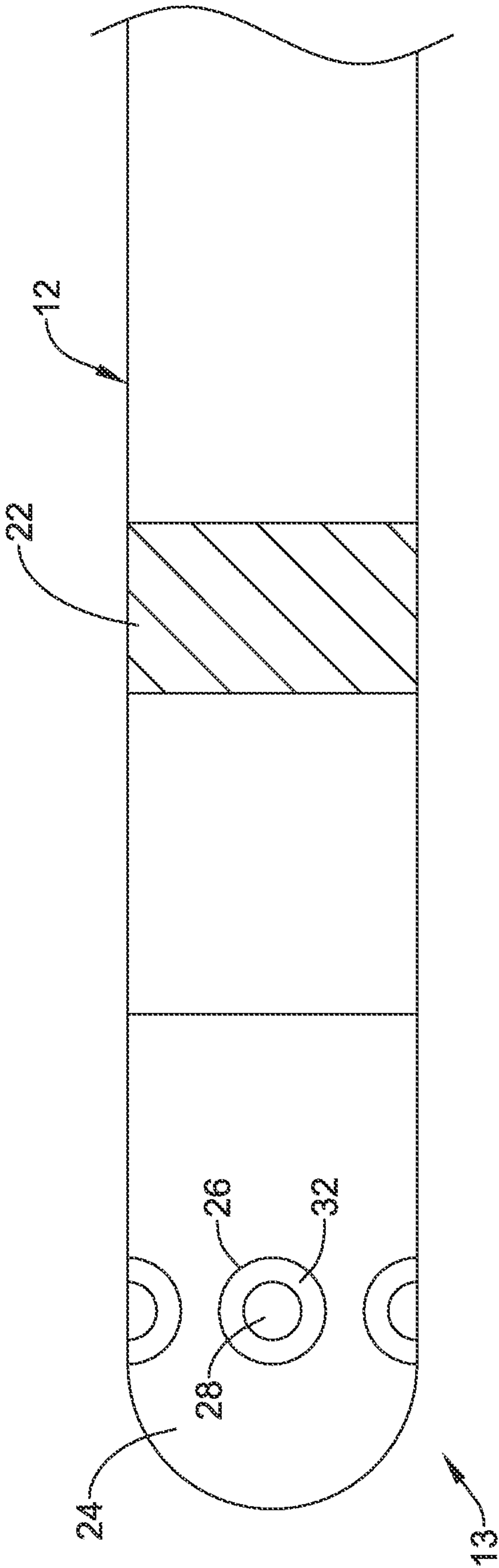


FIG. 2

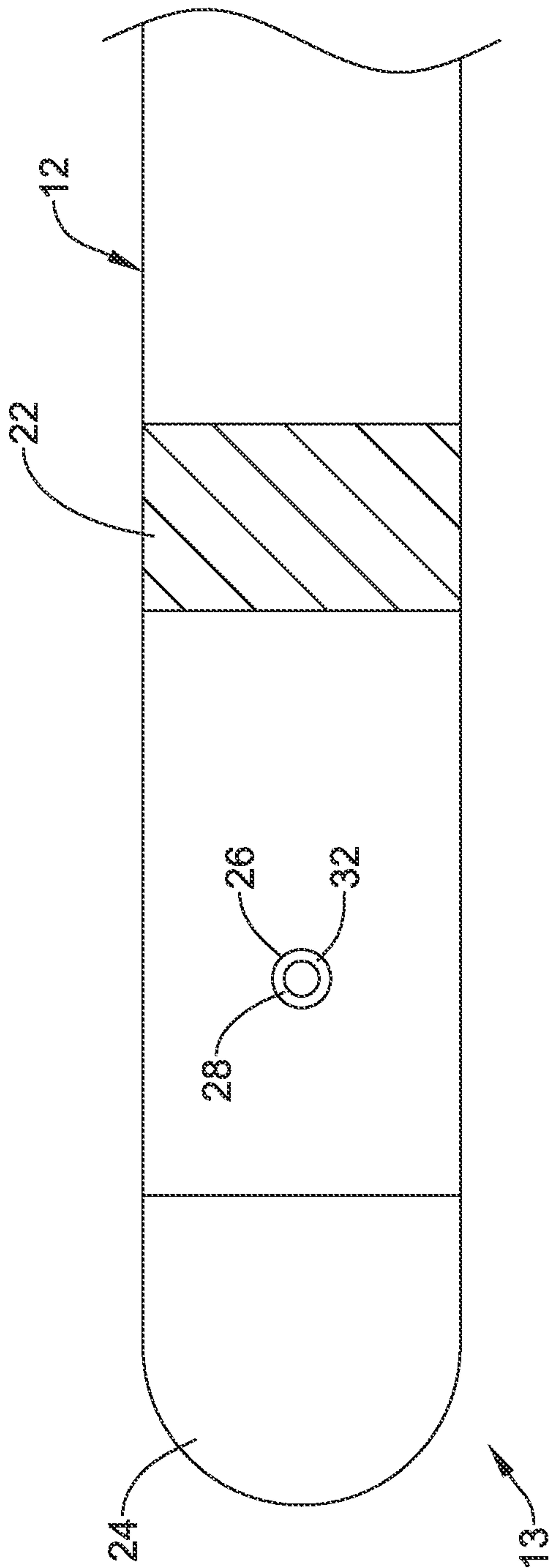


FIG. 3

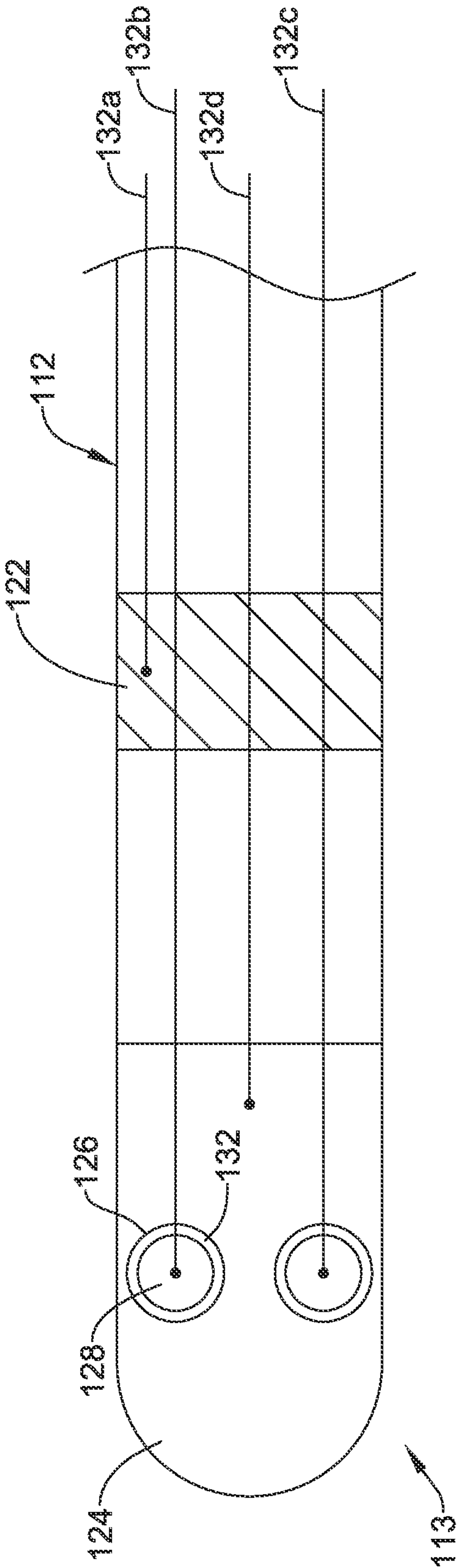


FIG. 4

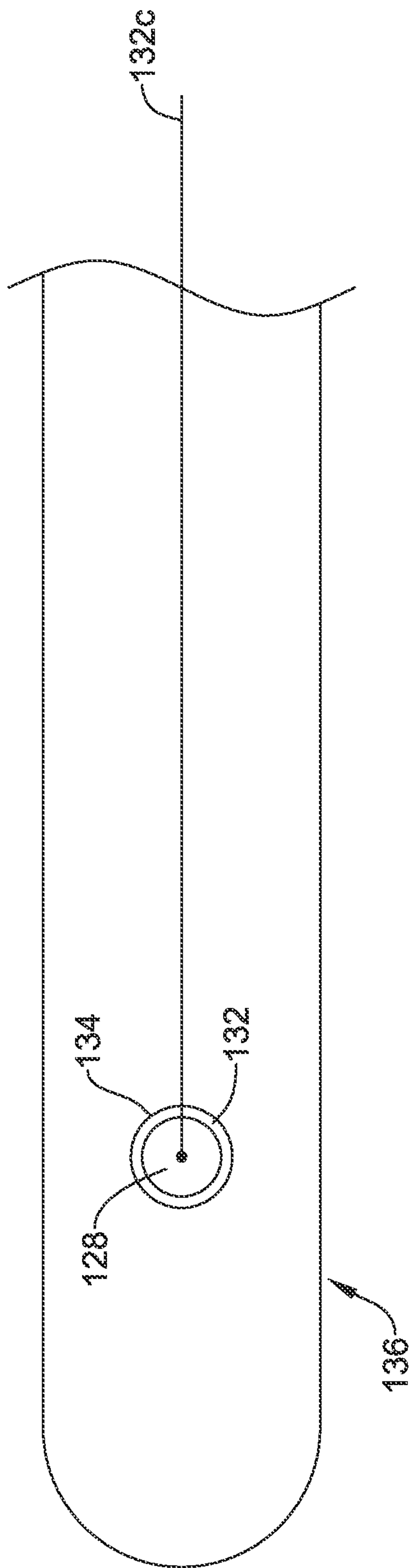
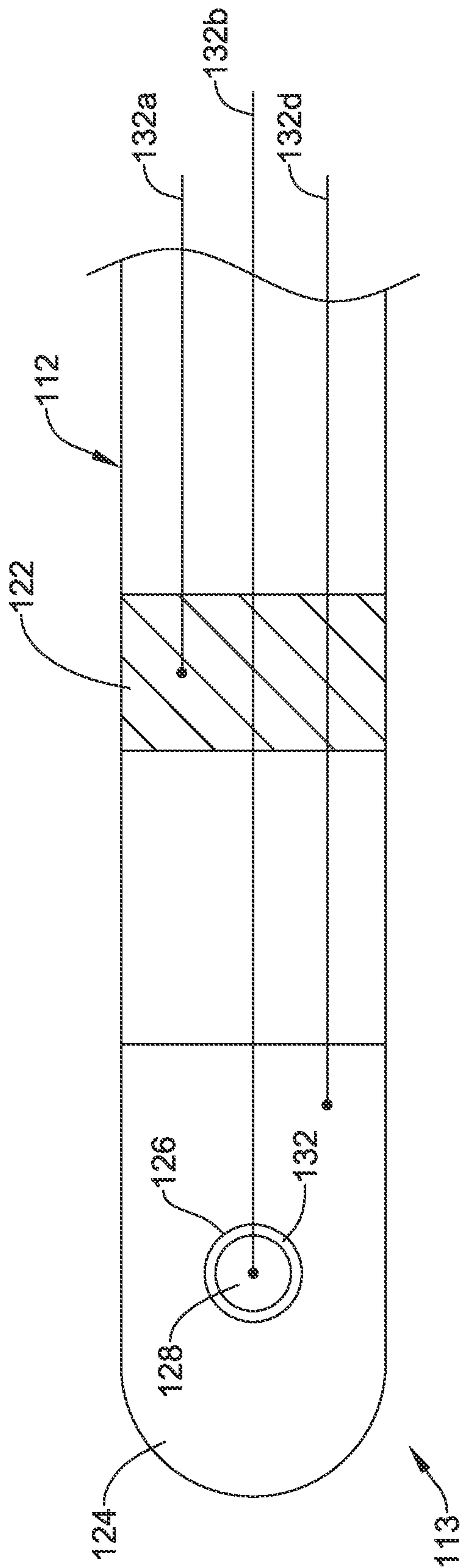


FIG. 5

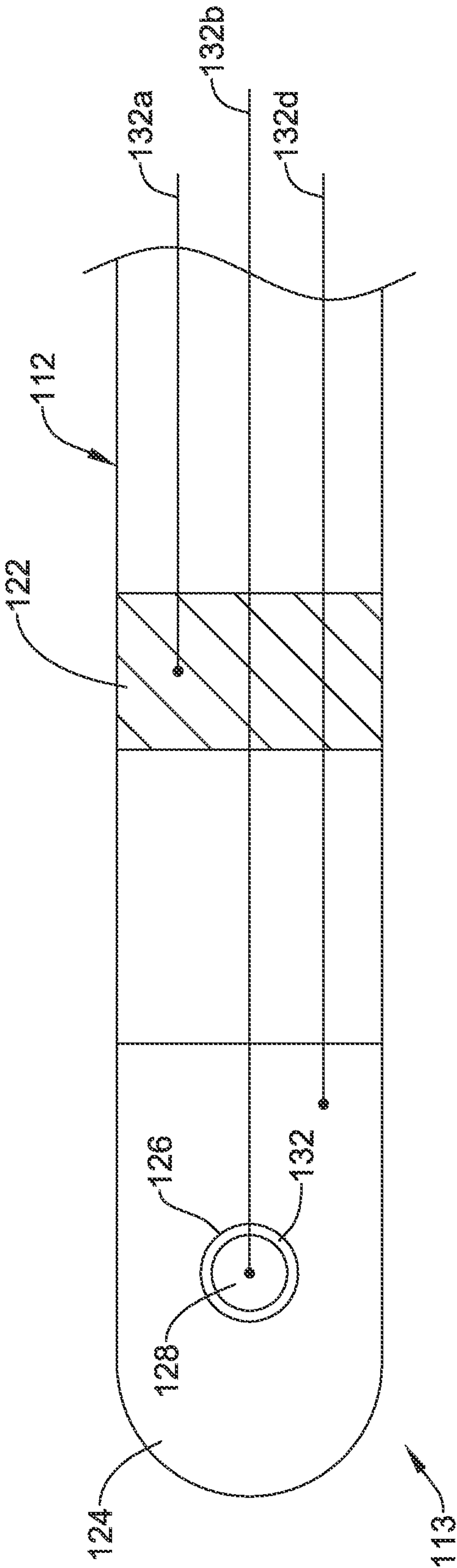


FIG. 6

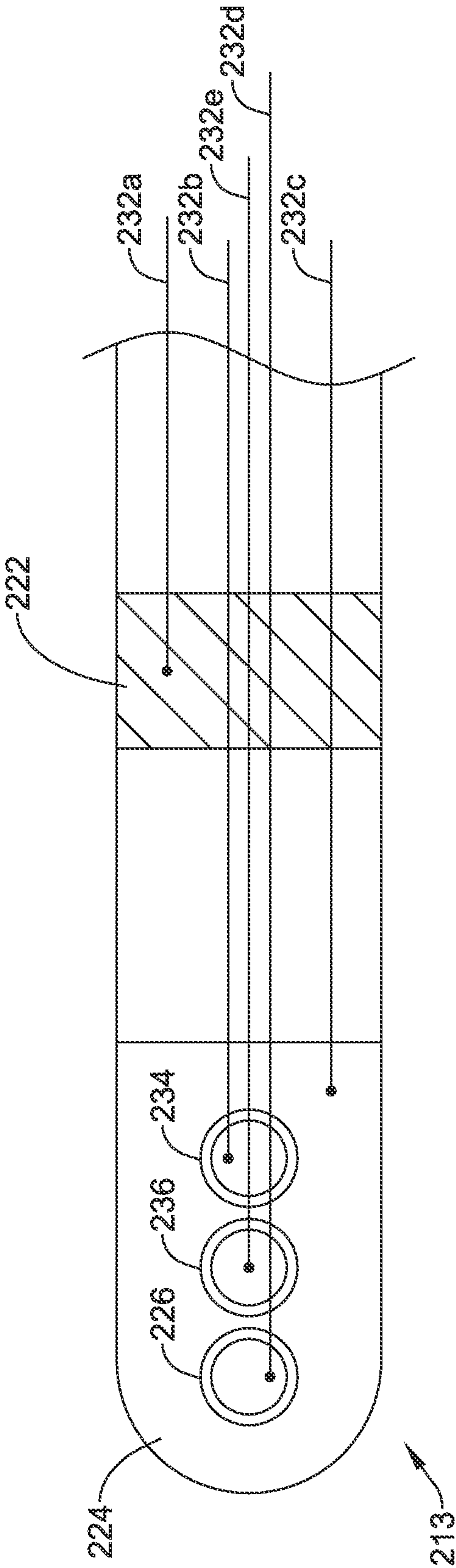


FIG. 7

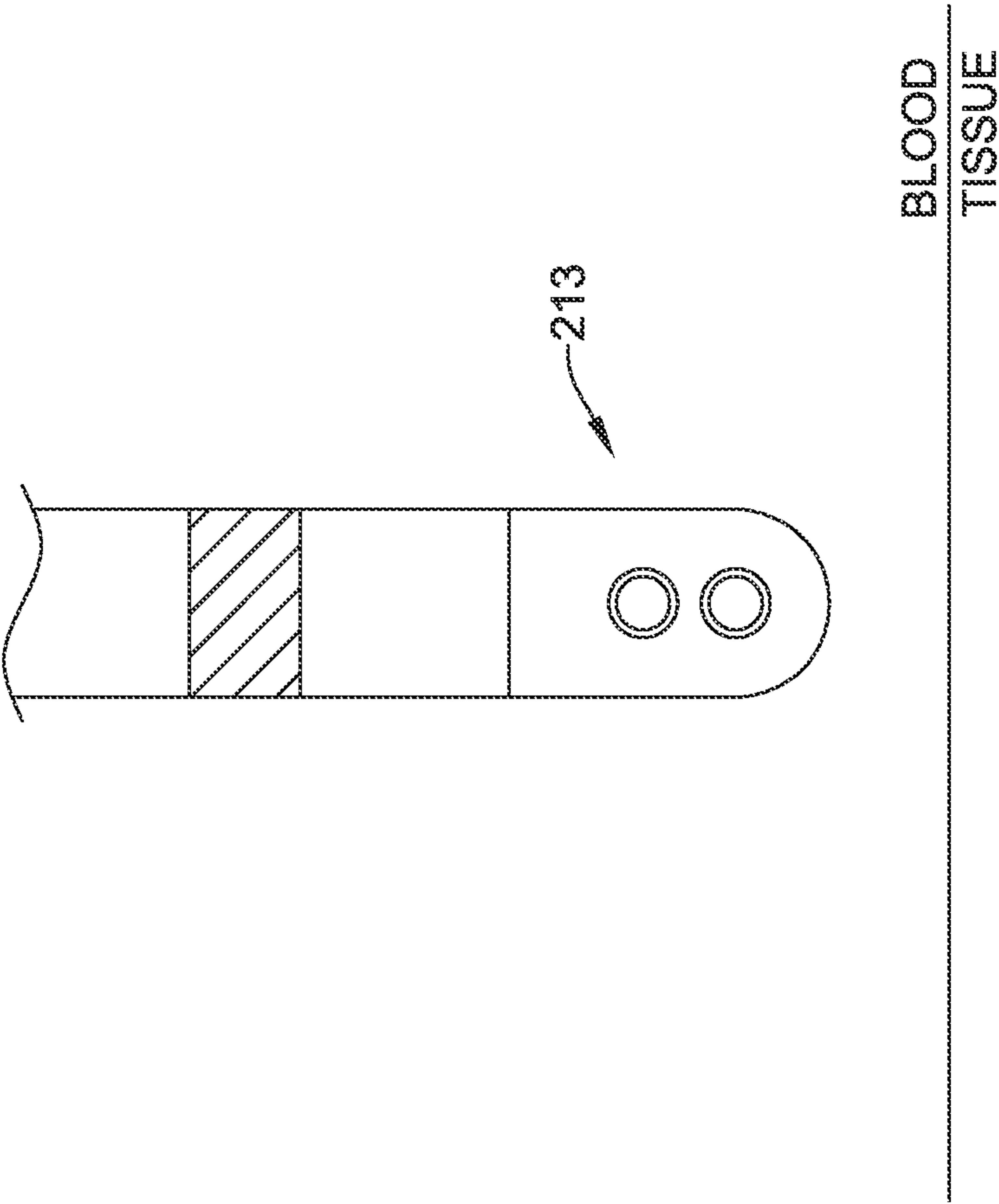


FIG. 8A

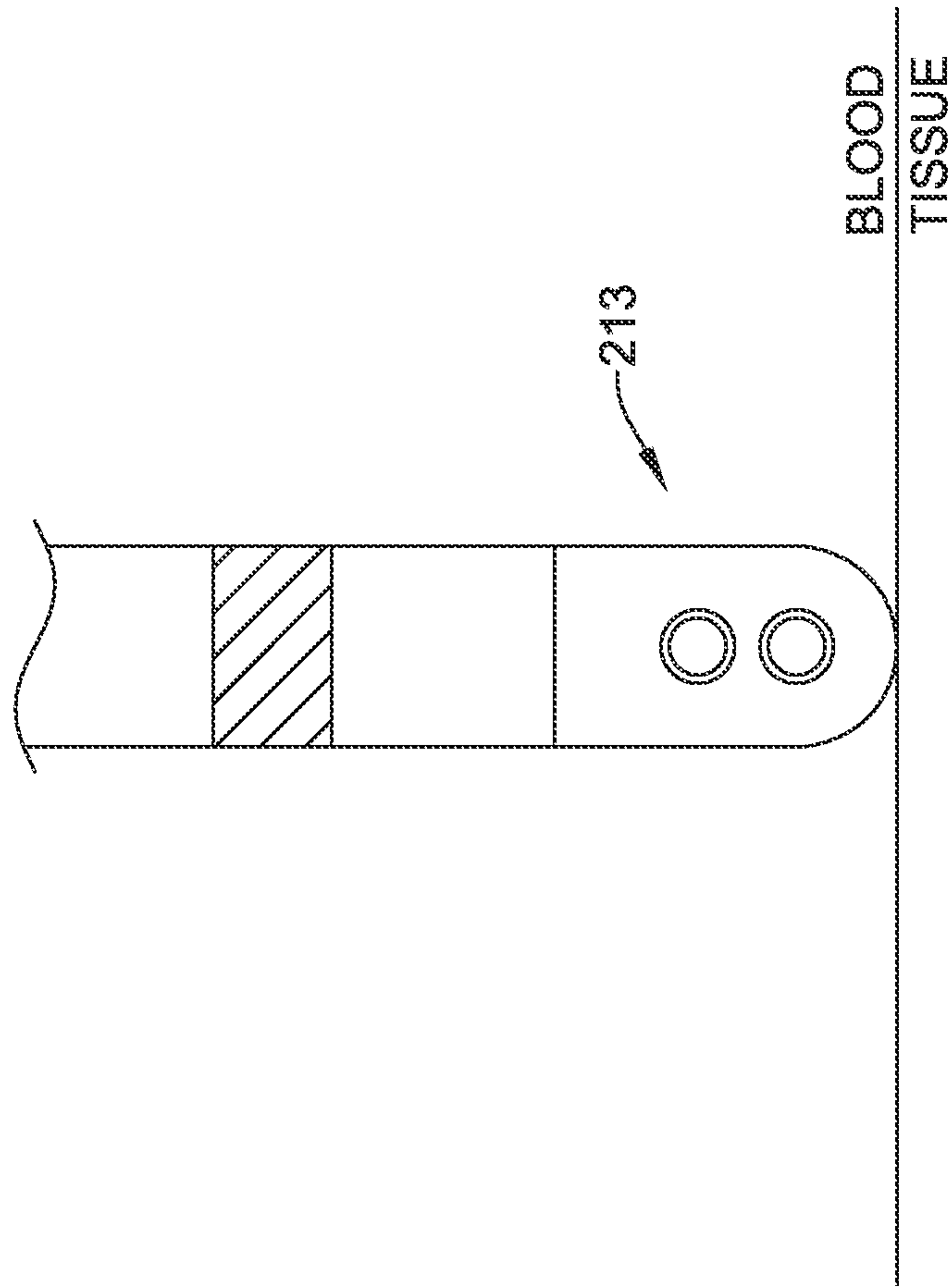


FIG. 8B

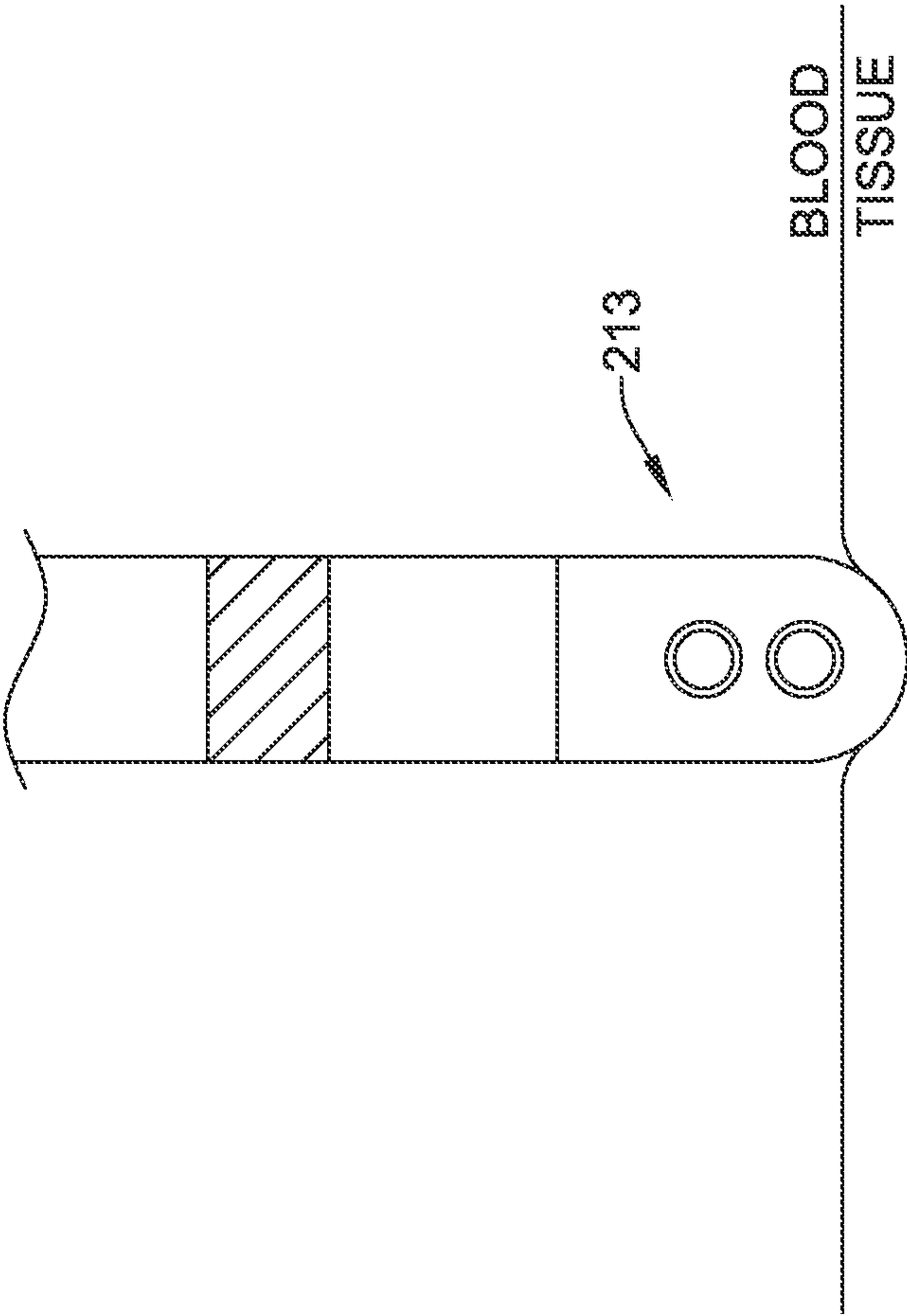


FIG. 8C

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TISSUE DIAGNOSIS AND TREATMENT USING MINI-ELECTRODES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to Provisional Application No. 62/063,296, filed Oct. 13, 2014, which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

The present disclosure pertains to medical devices, and methods for manufacturing medical devices. More particularly, the present disclosure pertains to tissue diagnosis and/or ablation.

BACKGROUND

A wide variety of intracorporeal medical devices have been developed for medical use, for example, intravascular use. Some of these devices include guidewires, catheters, and the like. These devices are manufactured by any one of a variety of different manufacturing methods and may be used according to any one of a variety of methods. Of the known medical devices and methods, each has certain advantages and disadvantages. There is an ongoing need to provide alternative medical devices as well as alternative methods for manufacturing and using medical devices.

SUMMARY

This disclosure provides design, material, manufacturing method, and use alternatives for medical devices. An example electrophysiology medical device may include a catheter shaft including a distal end portion and a sensing assembly having three or more terminals. The sensing assembly includes one or more current-carrying electrodes and one or more sensing electrodes. The one or more current-carrying electrodes, the one or more sensing electrodes, or both includes a mini-electrode. The mini-electrode is disposed on one of the other electrodes. The medical device may also include a controller coupled to the sensing assembly.

Additionally or alternatively to any of the examples above, the sensing assembly includes four terminals.

Additionally or alternatively to any of the examples above, one or more of the three or more terminals are disposed along the distal end portion of the catheter shaft.

Additionally or alternatively to any of the examples above, one or more of the three or more terminals are disposed along a device separate from the catheter shaft.

Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes at least one mini-electrode.

Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes at least two mini-electrodes.

Additionally or alternatively to any of the examples above, one or more sensing electrodes includes one mini-electrode.

Additionally or alternatively to any of the examples above, one or more sensing electrodes includes two mini-electrodes.

Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes a mini-electrode and one or more sensing electrodes includes two mini-electrodes.

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Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes two mini-electrodes and one or more sensing electrodes includes a mini-electrode.

5 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes two mini-electrodes and one or more sensing electrodes includes two mini-electrodes.

10 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes or one or more sensing electrodes includes an ablation electrode.

15 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes an ablation electrode and one or more sensing electrodes includes an electrode disposed on the ablation electrode.

20 Additionally or alternatively to any of the examples above, one or more sensing electrodes includes an ablation electrode and one or more current-carrying electrodes includes an electrode disposed on the ablation electrode.

25 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes or one or more sensing electrodes includes a ring electrode.

30 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes an ablation electrode and a ring electrode and the one or more sensing electrodes includes at least one mini-electrode.

35 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes at least one mini-electrode and one or more sensing electrodes includes an ablation electrode and a ring electrode.

40 Additionally or alternatively to any of the examples above, one or more current-carrying electrodes includes an ablation electrode and a mini-electrode and one or more sensing electrodes includes a ring electrode and a mini-electrode.

45 Additionally or alternatively to any of the examples above, one or more current-injecting electrodes includes a ring electrode and a mini-electrode and one or more sensing electrodes includes an ablation electrode and a mini-electrode.

50 Another example electrophysiology medical device may include a catheter shaft including a distal end portion. The distal end portion includes a plurality of electrodes. The plurality of electrodes includes at least one current-carrying electrode, a first sensing electrode and a second sensing electrode. Further, at least one of the electrodes is a mini-electrode disposed on another one of the other electrodes. The first sensing electrode is spaced from the current-carrying electrode a first distance. The second sensing electrode is spaced from the current-carrying electrode a second distance and the first distance is different from the second distance.

55 Additionally or alternatively to any of the examples above, the medical device may include a controller coupled to the plurality of electrodes. The at least one current-carrying electrode and the first and second sensing electrodes are arranged in a four-terminal sensing configuration and the controller is capable of calculating a parameter capable of indicating the proximity of the medical device to tissue.

60 An example method for diagnosing and/or treating a condition of the heart may include advancing an electrophysiology catheter through a blood vessel to a position adjacent a target site and utilizing the catheter to determine the proximity of the catheter to the target site. The catheter includes a distal end portion and a four-terminal sensing assembly disposed on the distal end portion. The four-

terminal sensing assembly includes one or more current-carrying electrodes and one or more sensing electrodes. One or more current-carrying electrodes and/or the one or more sensing electrodes includes a mini-electrode. The method may also include a controller coupled to the four-terminal sensing assembly.

The above summary of some embodiments is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The Figures, and Detailed Description, which follow, more particularly exemplify these embodiments.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may be more completely understood in consideration of the following detailed description in connection with the accompanying drawings, in which:

FIG. 1 is a plan view of an example tissue diagnosis and/or ablation system;

FIG. 2 illustrates an example medical device including a distal tip electrode, a ring electrode and mini-electrodes;

FIG. 3 illustrates an example medical device including a distal tip electrode, a ring electrode and a mini-electrode positioned away from the distal tip electrode and/or ring electrode;

FIG. 4 illustrates an example medical device including a distal tip electrode, a ring electrode and mini-electrodes arranged in a four-terminal sensing configuration;

FIG. 5 illustrates two example medical devices arranged in a four-terminal sensing configuration having one mini-electrode positioned separate from an ablation electrode and/or ring electrode;

FIG. 6 illustrates an example medical device including a distal tip electrode, a ring electrode and mini-electrodes arranged in a three-terminal sensing configuration;

FIG. 7 illustrates an example medical device including a current injecting electrode and four potential measuring electrodes;

FIGS. 8a-8c illustrates an example medical device positioned relative to two different mediums.

While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

DETAILED DESCRIPTION

For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

All numeric values are herein assumed to be modified by the term “about”, whether or not explicitly indicated. The term “about” generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (e.g., having the same function or result). In many

instances, the terms “about” may include numbers that are rounded to the nearest significant figure.

The recitation of numerical ranges by endpoints includes all numbers within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5).

As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” include plural referents unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.

It is noted that references in the specification to “an embodiment”, “some embodiments”, “other embodiments”, etc., indicate that the embodiment described may include one or more particular features, structures, and/or characteristics. However, such recitations do not necessarily mean that all embodiments include the particular features, structures, and/or characteristics. Additionally, when particular features, structures, and/or characteristics are described in connection with one embodiment, it should be understood that such features, structures, and/or characteristics may also be used connection with other embodiments whether or not explicitly described unless clearly stated to the contrary.

The following detailed description should be read with reference to the drawings in which similar elements in different drawings are numbered the same. The drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the invention.

Cardiac arrhythmia and/or other cardiac pathology contributing to abnormal heart function may originate in cardiac cellular tissue. One technique that may be utilized to treat the arrhythmia and/or cardiac pathology may include ablation of tissue substrates contributing to the arrhythmia and/or cardiac pathology. The tissue in the substrate may be electrically disrupted, or ablated, by heat, chemicals or other means of creating a lesion in the tissue, or otherwise can be electrically isolated from the normal heart circuit. Electrophysiology therapy involves locating the tissue contributing to the arrhythmia and/or cardiac pathology using an ablation, mapping and/or diagnosing catheter and then using the ablation catheter (or another device) to destroy and/or isolate the tissue.

Prior to performing an ablation procedure, a physician and/or clinician may utilize specialized mapping and/or diagnostic catheters to precisely locate tissue contributing and/or causing an arrhythmia or other cardiac pathology. It may, therefore, be desirable to be able to precisely locate the targeted tissue prior to performing the ablation procedure in order to effectively alleviate and/or eliminate the arrhythmia and/or cardiac pathology. Further, precise targeting of the tissue may prevent or reduce the likelihood that healthy tissue (located proximate the targeted tissue) is damaged.

Several methods and/or techniques may be employed to precisely locate targeted tissue where an ablation or other therapeutic procedure may be performed. An example method may include utilizing an ablation, mapping and/or diagnostic catheter to determine how close the catheter is to targeted tissue. Further, the ablation, mapping and/or diagnostic catheter may include one or more sensing electrodes located on a distal portion of the catheter. The electrodes may sense, measure and/or provide a controller with information relating to electrical activity within the cardiac tissue. Using the sensed and/or measured electrical information from cardiac tissue, the controller may be able to correlate the spatial location of the distal portion of the catheter in relation to the cardiac tissue. For example, the

electrodes may measure the impedance, resistance, voltage potential, etc. and determine how far a distal portion of a diagnostic and/or ablation catheter is to cardiac tissue.

Electrodes utilized in conjunction with an ablation, mapping and/or diagnostic catheter are often located on the distal portion and/or distal end of the catheter. For example, an ablation catheter may include a distal tip electrode and one or more ring electrodes located proximal the distal tip electrode. The distal tip electrode may be able to sense and/or measure electrical activity in addition to being able to provide ablative therapy as an ablation electrode. The ring electrodes may be used as sensing and/or measuring electrodes in conjunction with one another and/or the ablation electrode.

In general, the size and/or spacing of electrodes may contribute to the accuracy of the electrical information sensed and/or measured by the mapping and/or diagnostic catheter. For example, some methods and/or techniques may emit a current from a first electrode and measure the impedance (or other electrical characteristic) of local tissue using a different pair of electrodes. However, a current emitted from an electrode having a large surface area may not be as concentrated as compared to a current emitted from an electrode having a (proportionally) smaller surface area. A smaller electrode surface area may have a tendency to focus and/or direct current to tissue immediately adjacent the emitting and/or measuring electrodes.

Further, in some circumstances it may be challenging to position an ablation tip and/or ring electrodes precisely adjacent targeted tissue due to the relatively large size of the tip and/or a ring electrode. In particular, it may be challenging to arrange larger electrodes in an optimally-spaced configuration because the size and shape of larger electrodes may limit how close the electrodes can be placed to one another.

In addition, larger electrodes may be more susceptible (as compared to smaller electrodes) to detecting far field electrical activity. Detection of far field electrical activity may negatively affect the detection of local (e.g. targeted) electrical activity.

Therefore, it may be desirable in some instances to utilize, dispose, incorporate and/or couple smaller electrodes (e.g. mini-electrodes) into the distal portion of mapping and/or diagnostic catheters. For example, some of the medical devices and methods disclosed herein may include sensing and measuring electrical activity using mini-electrodes alone or in conjunction with ablation electrodes, ring electrodes, catheters and/or other medical devices. Further, some of the medical devices and methods disclosed herein may utilize electrical information collected from mini-electrodes to assess tissue proximity and/or contact. Other methods and medical devices are also disclosed.

FIG. 1 illustrates an example cardiac mapping and/or ablation system 10. As shown in FIG. 1, system 10 may include an elongated member or catheter shaft 12, an RF generator 14, and a controller 16 (e.g., a mapping processor, ablation processor, and/or other processor). Illustratively, shaft 12 may be operatively coupled to at least one or more (e.g., one or both) of RF generator 14 and controller 16. Alternatively, or in addition, a device (other than shaft 12), may be utilized to apply ablation energy and/or diagnose a target area and may be operatively coupled to at least one or more of RF generator 14 and controller 16. RF generator 14 may be capable of delivering and/or may be configured to deliver ablation energy to shaft 12 in a controlled manner in order to ablate target area sites identified by controller 16. Although the controller 16 and RF generator 14 may be

shown as discrete components, these components or features of components may be incorporated into a single device. System 10 may include any of one or more other features, as desired.

In at least some embodiments, shaft 12 may include a handle 18, which may have an actuator 20 (e.g., a control knob or other actuator). The handle 18 (e.g., a proximal handle) may be positioned at a proximal end of shaft 12, for example. Illustratively, shaft 12 may include a flexible body having a distal portion which may include one or more electrodes. For example, the distal portion of shaft 12 may include one or more of a plurality of ring electrodes 22, a distal ablation tip electrode 24, and a plurality of mini-electrodes 26 disposed or otherwise positioned along and/or electrically isolated from distal ablation tip electrode 24.

Shaft 12 may be steerable to facilitate navigating the vasculature of a patient or navigating other lumens. Illustratively, a distal portion 13 of shaft 12 may be deflected by manipulation of actuator 20 to effect steering shaft 12. In some instances, distal portion 13 of shaft 12 may be deflected to position distal ablation tip electrode 24 and/or mini-electrodes 26 adjacent target tissue or to position the distal portion 13 of shaft 12 for another suitable purpose. Additionally, or alternatively, distal portion 13 of shaft 12 may have a pre-formed shape adapted to facilitate positioning distal ablation tip electrode 24 and/or micro-electrode assemblies 26 adjacent a target tissue. Illustratively, the preformed shape of distal portion 13 of shaft 12 may be a radiused shape (e.g., a generally circular shape or a generally semi-circular shape) and/or may be oriented in a plane transverse to a general longitudinal direction of shaft 12. These are just examples.

In some instances, system 10 may be utilized in ablation procedures on a patient. Illustratively, shaft 12 may be configured to be introduced into or through vasculature of a patient and/or into or through any other lumen or cavity. In one example, shaft 12 may be inserted through the vasculature of the patient and into one or more chambers of the patient's heart (e.g., a target area). When in the patient's vasculature or heart, shaft 12 may be used to map and/or ablate myocardial tissue using the ring electrodes 22, mini-electrodes 26, and/or distal ablation tip electrode 24. In some instances, distal ablation tip electrode 24 may be configured to apply ablation energy to myocardial tissue of the heart of a patient.

Distal ablation tip electrode 24 may be a suitable length and include a suitable surface area. In some instances, distal ablation tip electrode 24 may have a length of between one (1) mm and twenty (20) mm, three (3) mm and seventeen (17) mm, or six (6) mm and fourteen (14) mm. In one illustrative example, distal ablation tip electrode 24 may have an axial length of about eight (8) mm. Further, distal ablation tip electrode may have a suitable surface area of between five (5) mm² and one hundred (100) mm², ten (10) mm² and eighty (80) mm², or twenty (20) mm² and seventy (70) mm². In one illustrative example, distal ablation tip electrode 24 may have a surface area of about twenty-nine (29) mm². Distal ablation tip electrode 24 may be formed from or otherwise include platinum and/or other suitable materials. These are just examples.

As stated, mini-electrodes 26 may be circumferentially distributed about a distal ablation tip electrode 24. Mini-electrodes 26 may be capable of operating, or configured to operate, in unipolar or bipolar sensing modes. Mini-electrodes 26 may be capable of sensing, or may be configured to sense, electrical characteristics (e.g. impedance) corresponding to myocardial tissue proximate thereto.

For example, in some instances system 10 may be capable of utilizing impedance measurements to sense contact between the catheter tip (e.g. distal ablation tip electrode 24) and tissue. In general, the impedance of a given medium may be measured by applying a known voltage or current to a given medium and measuring the resulting voltage or current. In other words, impedance measurements of a given medium can be obtained by injecting current between two electrodes and measuring the resulting voltage between the same electrodes through which the current was injected. The ratio of the voltage potential to the applied current provides an indication of the impedance of the medium through which the current traveled.

For example, FIG. 1 illustrates that current may be injected between distal ablation tip electrode 24 and a ring electrode 22. Impedance of the medium (e.g. tissue) adjacent to distal ablation tip electrode 24 and ring electrode 22 may be measured according to the methodology disclosed above. For example, if the distal ablation tip electrode 24 and ring electrode are embedded in cardiac tissue, the impedance of the cardiac tissue may be determined.

In some instances, contact system 10 may utilize different impedance measurements of a local medium to determine whether the distal ablation tip electrode 24 is contacting tissue. For example, the impedance of cardiac tissue is different than that of blood. Therefore, by knowing the relative difference in the impedance of tissue versus blood, system 10 may be able to determine whether the medium through which a current is being applied is either blood or cardiac tissue, for example.

In some examples, mini-electrodes 26 may be operatively coupled to controller 16. Further, generated output from mini-electrodes 26 may be sent to controller 16 of system 10 for processing in one or more manners discussed herein and/or for processing in other manners. As stated, an electrical characteristic (e.g. impedance) and/or an output signal from a mini-electrode pair may at least partially form the basis of a contact assessment, ablation area assessment (e.g., tissue viability assessment), and/or an ablation progress assessment (e.g., a lesion formation/maturation analysis), as discussed below.

Further, system 10 may be capable of processing or may be configured to process the electrical signals from mini-electrodes 26, ring electrodes 22, and/or distal ablation tip electrode 24. Based, at least in part, on the processed output from mini-electrodes 26, ring electrodes 22, and/or distal ablation tip electrode 24, controller 16 may generate an output to a display (not shown) for use by a physician or other user. In instances where an output is generated to a display and/or other instances, controller 16 may be operatively coupled to or otherwise in communication with the display. Illustratively, the display may include various static and/or dynamic information related to the use of system 10. In one example, the display may include one or more of an image of the target area, an image of shaft 12, and/or indicators conveying information corresponding to tissue proximity, which may be analyzed by the user and/or by a processor of system 10 to determine the existence and/or location of arrhythmia substrates within the heart, to determine the location of shaft 12 within the heart, and/or to make other determinations relating to use of shaft 12 and/or other elongated members.

System 10 may include an indicator in communication with controller 16. The indicator may be capable of providing an indication related to a feature of the output signals received from one or more of the electrodes of shaft 12. In one example, an indication to the clinician about a charac-

teristic of shaft 12 and/or the myocardial tissue interacted with and/or being mapped may be provided on the display. In some cases, the indicator may provide a visual and/or audible indication to provide information concerning the characteristic of shaft 12 and/or the myocardial tissue interacted with and/or being mapped. For example, system 10 may determine that a measured impedance corresponds to an impedance value of cardiac tissue and therefore may output a color indicator (e.g. green) to a display. The color indicator may allow a physician to more easily determine whether to apply ablative therapy to a given cardiac location. This is just an example. It is contemplated that a variety of indicators may be utilized by system 10.

In the above disclosure, the ability for system 10 to accurately measure impedance values may depend on the relative distribution of current density being applied to a given medium. For example, the size of the electrode from which current is emitted may lead to current diffusion through non-targeted, surrounding tissue. When comparing the current density of two electrodes, one of which is proportionally larger than the other, the electrode with less surface area may concentrate an electrical current to localized tissue to a greater extent than the larger electrode. Therefore, it may be challenging to get accurate current delivery at discrete spatial points in cardiac tissue when utilizing proportionally larger electrodes.

Additional details regarding mini-electrodes 26, distal ablation tip electrode 24 and ring electrode 22 are shown in FIG. 2. FIG. 2 illustrates that mini-electrodes 26 may include "inner" electrode 28. Further, a layer of insulation 32 may be disposed around inner electrode 28. In embodiments where mini-electrodes 26 are disposed along distal ablation tip electrode 24, insulation 32 may insulate inner electrode 28 from distal ablation tip electrode 24, ring electrode 22 and/or other inner electrodes 28. In some embodiments, insulation 32 may surround and isolate inner electrode 28 from ablation tip electrode 24.

As shown in FIG. 2, mini-electrodes 26 may be positioned such that there is minimal space between adjacent mini-electrodes 26. Further, the smaller size of mini-electrodes 26 (relative to distal ablation tip electrode 24, for example) may allow mini-electrodes to be positioned in multiple configurations. For example, mini-electrodes 26 may circumferentially aligned as shown in FIG. 2. Additionally, mini-electrodes 26 may be offset in a variety of different configurations. For example, mini-electrodes 26 may be positioned longitudinally along the longitudinal axis of shaft 12 or may be positioned on the apex of distal ablation tip electrode 24.

It is contemplated that mini-electrodes 26 may have a suitable exposed surface area of between 0.20 mm² and 1 mm², 0.30 mm² and 0.80 mm², or 0.40 mm² and 0.70 mm². In one embodiment, mini-electrodes 26 may have a suitable exposed surface area of 0.50 mm². Comparison of the ratio of the suitable exposed surface area of mini-electrodes 26 to that of distal ablation tip electrode 24 shows that the suitable exposed surface area of distal ablation tip electrode 24 may be at least ten (10) times larger, fifteen (15) times, or twenty (20) times larger than the suitable surface area of mini-electrodes 26. These are just examples. The ratio of the suitable exposed surface area of distal tip electrode 24 to the suitable exposed surface area of mini-electrode 26 may be less than or greater than twenty (20). For example, the ratio of the suitable exposed surface area of distal tip electrode 24 to the suitable exposed surface area of mini-electrode 26 may be 30, 50, or 100. Further, the ratio of the suitable exposed surface area of distal tip electrode 24 to the suitable

exposed surface area of mini-electrode **26** may be less than one hundred seventy five (175).

Alternatively, mini-electrodes **26** may be used in conjunction with distal ablation tip electrode **24**, with ring electrode **22**, or alone. Additionally, because mini-electrodes **26** may be proportionally smaller than either distal ablation tip electrode **24** and/or ring electrode **22**, mini-electrodes **26** may be positioned in many different spatial configurations with respect to distal ablation tip electrode **24** and/or ring electrode **22**. For example, as shown in FIG. **2**, mini-electrodes **26** may be disposed “on” distal ablation tip electrode **24**. As discussed herein, mini-electrodes **26** may be described as being “on,” “along,” and/or otherwise embedded and/or encased on a given structure. This is not intended to be limiting. Rather, mini-electrodes **26** can be positioned and/or otherwise located at any suitable position/location along the distal tip and/or at other locations along the catheter and/or other remote structure. Positioning/locating the electrodes may include embedding, partially embedding, encasing, partially encasing, isolating, attaching, affixing, fastening, bonding to the outer surface, embedding within the wall, or the like.

Even though much of the discussion herein has been directed to embodiments in which mini-electrodes **26** have been positioned “on” distal ablation tip electrode **24**, it is further contemplated that one or more mini-electrodes may be positioned along the catheter shaft at a position that is away from distal ablation tip electrode **24** and continue to function substantially equivalent to those embodiments in which mini-electrodes are positioned “on” distal tip ablation electrode **24**.

For example, FIG. **3** shows mini-electrode **26** disposed on shaft **12** away from distal ablation tip electrode **24**. Further, as discussed above, mini-electrode **26** disposed away from distal ablation tip electrode **24** may be positioned “on” catheter shaft **12** or any other portion of ablation system **10**. Additionally, mini-electrodes **26** may be “on” other electrodes (e.g. ring electrode, etc.). As stated above, mini-electrode **26** may be substantially smaller than distal ablation tip electrode **24**. As illustrated in FIG. **3**, mini-electrode **26** is substantially smaller than distal ablation tip electrode **24**.

Further, the size of mini-electrodes **26** may allow mini-electrodes **26** to be placed directly adjacent to tissue for which an ablation, diagnostic and/or therapeutic procedure may be performed. For example, as discussed above, in order to determine tissue contact through impedance measurements, the current for which a voltage ratio (and hence, impedance) is measured must pass through the medium (e.g. tissue) for which the targeted impedance value is sought. If the current is diffused and/or passes primarily through a non-targeted medium (e.g. blood), the observed impedance value may not accurately represent whether the catheter is in contact with the desired medium (e.g. tissue).

Due to their relatively small size, mini-electrodes **26** may be placed precisely at a discrete point in space. Further, it may be desirable to inject current between mini-electrodes **26** positioned at a discrete point in space. It can be appreciated that measurements (e.g. impedance) derived from mini-electrodes **26** may reflect the medium adjacent to a discrete point in space. For example, positioning and driving current through closely positioned mini-electrodes **26** may provide greater confidence that impedance measurements derived therefrom are accurate.

Further, it may be desirable to position mini-electrodes **26** close to distal ablation tip electrode **24** and/or ring electrode **22**. For example, disposing closely-positioned mini-electrodes

26 directly on distal ablation tip **24** may provide confidence that distal ablation tip **24** is, in fact, in contact with a given medium reflected by a particular impedance measurement.

As stated above, injecting current through mini-electrodes **26** (versus a larger distal ablation tip electrode **24** and/or ring electrode **22**) may improve measurements by concentrating the current path precisely through a localized medium. Diffusion of current through surrounding tissue may be reduced by injecting current through the smaller surface area of mini-electrode **26** versus a larger surface area electrode.

Additionally or alternatively, improvement in the measurement of impedance may be accomplished by using a four-terminal sensing configuration. In general, a four-terminal sensing configuration drives current through a pair of electrodes (similar to that discussed above) and measures the voltage across a different pair of electrodes. For ease of understanding the foregoing discussion, the electrode pair between which current is injected in a four-terminal sensing configuration will be hereafter referred to as the “current-carrying” electrode pair. The electrode pair across which voltage is measured will be referred to as the “sensing” electrode pair.

One advantage of a four-terminal sensing configuration is that the measured impedance may not be sensitive to the impedance of the electrodes. In a two-terminal sensing configuration, the measured impedance includes the surrounding medium and both electrodes. In contrast, a four-terminal sensing configuration measures voltage across electrodes through which the current is negligible. As a result, the measured impedance is that of the surrounding medium and is largely independent of the impedance of the electrode and its interface with the surrounding medium.

For example, FIG. **4** illustrates a four-terminal sensing configuration using distal ablation tip electrode **124**, ring electrode **122** and two mini-electrodes **126**. Additionally, FIG. **4** shows lead wires **132a-132d**. Lead wires **132a-132d** may connect any given electrode to controller **16**, RF generator **14** or both. Lead wires **132a-132d** may also connect individual electrodes to one another in a variety of configurations.

Referring to FIG. **4**, the distal ablation tip electrode **124** and ring electrode **122** may define the current-carrying electrode pair. Further, the pair of mini-electrodes **126** may define the sensing electrode pair. Therefore, current may be injected between the distal ablation tip electrode **126** and the ring electrode **122**, and voltage may be measured across mini-electrodes **126**. It can be appreciated that in this example, impedance measurements may be the impedance of the medium adjacent the sensing electrode pair. For example, if the distal portion **13** of system **10** is embedded in tissue, mini-electrodes **126** may measure the impedance of tissue adjacent mini-electrodes **126**. It should be understood that one advantage of using a four-terminal system with mini-electrodes **126** is that precise measurements of impedance (or other electrical characteristics) may be obtained at a discrete point.

Additionally or alternatively, a variety of combinations, arrangements and/or configurations may incorporate a variety of electrodes (e.g. distal ablation tip electrode, ring electrode, mini-electrode, remote reference electrode, etc.) in a four-terminal sensing configuration. In some combinations (e.g. the combinations illustrated in FIG. **3** or FIG. **4**), the electrodes may be disposed on distal portion **13/113** of catheter shaft **12/112**. In other combinations, one or more of the electrodes in a four-terminal sensing configuration may not be disposed on catheter shaft **12/112** and/or distal portion

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13/113. Rather, some electrodes may be located off of and away from catheter shaft 12/112 and/or distal portion 13/113.

For example, FIG. 5 shows electrode 134 located away from catheter shaft 112 and distal portion 113. In this example, electrode 134 is located on catheter shaft 136, which is different from or otherwise separate from catheter shaft 112. Even though FIG. 5 shows electrode 134 disposed on catheter shaft 136, it is contemplated that electrode 134 may be located or disposed on any structure away from catheter shaft 112. For example, electrode 134 may be disposed on the surface of a patient's body or disposed on another portion of ablation system 10. These are just examples, other combinations and/or remote structures are contemplated.

Similar to that discussed above with respect to FIGS. 2-4, one or more of the electrodes in a four-terminal sensing configuration that are remote and/or disposed away from catheter shaft 112 may be positioned "on" the structure in which they are disposed. Further, as stated above, any given electrode may be disposed on another electrode yet operate independently of the electrode on which it is disposed (e.g. mini-electrodes 126 disposed on and insulated from distal ablation tip electrode 124).

Additionally or alternatively, a four-terminal sensing configuration may be implemented and/or configured using only three electrodes. In some instances, a single electrode (e.g. distal ablation tip electrode, ring electrode, mini-electrode, remote electrode, etc.) may operate as both a current-carrying and sensing electrode. In this case, the measured impedance may include the impedance of the electrode used for both purposes (e.g., current-carrying and sensing) as well as the impedance of the electrode's interface with the surrounding medium. This configuration may approximate the four-terminal configuration if the impedance of the electrode is low or is not expected to vary significantly. Including the impedance of one of the electrodes (and its interface) may be desirable in some cases, particularly if that impedance varies significantly with tissue contact.

FIG. 6 illustrates a three-terminal sensing configuration. In FIG. 6, any one of distal ablation tip electrode 124, mini-electrode 126 or ring electrode 122 may operate as both a current-carrying and sensing electrode. Further, any of the embodiments and/or configurations discussed with respect to FIGS. 2-5 (e.g. the four-terminal sensing configuration) may be implemented in the three-terminal configuration.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include one or more mini-electrodes 126, while the sensing electrode pair may include the distal tip ablation electrode 124 and/or ring electrode 122.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include a distal tip ablation electrode 124 and a mini-electrode 126, while the sensing electrode pair may include one or more mini-electrodes 126.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include one or more mini-electrodes 126, while the sensing electrode pair may include a distal tip ablation electrode 124 and one or more mini-electrodes 126.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include one or more mini-electrodes 126, while the sensing electrode pair may include a ring electrode 122 and one or more mini-electrodes 126.

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In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include a ring electrode 122 and one or more mini-electrodes 126, while the sensing electrode pair may include one or more mini-electrodes 126.

In another example of a four-terminal sensing configuration, all the electrodes in the four-terminal sensing configuration may be mini-electrodes 126.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include one mini-electrode 126 and distal tip ablation electrode 124, while the sensing electrode pair may include one or more mini-electrode 126 and ring electrode 122.

In another example of a four-terminal sensing configuration, the sensing electrode pair may include one mini-electrode 126 and distal tip ablation electrode 124, while the current-carrying electrode pair may include one or more mini-electrode 126 and ring electrode 122.

In another example of a four-terminal sensing configuration, the current-carrying electrode pair may include one mini-electrode 126, while the sensing electrode pair may include the distal tip ablation electrode 124.

In another example of a four-terminal sensing configuration, the sensing electrode pair may include one mini-electrode 126, while the current-carrying electrode pair may include the distal tip ablation electrode 124.

It is contemplated that the controller 16 may incorporate an algorithm that controls the various electrodes in the desired manner in order to assess contact. This might include powering the electrodes in the manner disclosed herein. This may also include more than one sensing configuration, with the sensing configurations multiplexed in time, frequency, or both.

While the above discussion indicates that mini-electrodes may be used for tissue contact sensing, this is not intended to be limiting. Rather, the mini-electrodes may be used for a variety of functions including ablation, mapping, sensing, or the like.

As stated, the impedance, resistance, voltage and/or other output obtained from any of the above described four-terminal sensing configurations may be displayed for diagnostic use by a physician or clinician. For example, a four-terminal sensing configuration may measure and/or sense the impedance of tissue, and output a corresponding indicator (as described above) to a display. The display may be connected to controller 16, RF generator 14 and/or to any other component of system 10.

In addition or alternatively to that disclosed above, another method for assessing tissue contact may include determining a parameter of a model and observing changes in the parameter as the distal end portion 13 of catheter 12 moves between different mediums (e.g. as between blood and tissue).

For example, a scaling factor may be a parameter in a model used for this purpose. The model may relate to one or more potential differences between one or more sensing electrodes and a reference electrode. A reference electrode may be an electrode placed a distance away from the potential measuring electrodes. For example, a reference electrode may be placed on the back of a patient.

Sensing electrodes may be disposed on the tip and/or end of distal portion 13 of a catheter. In some examples, sensing electrodes may include mini-electrodes as described herein.

Additionally or alternatively, the model may also relate to the distance in space between a current-carrying electrode and one or more sensing electrodes. The current-carrying electrode may take a variety of forms. For example, the

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current-carrying electrode may be a distal ablation tip electrode **24** as shown in FIG. **1**. Additionally or alternatively, the current-carrying electrode may include mini-electrodes and/or ring electrodes as described above with reference to FIGS. **1** and **2**.

In some configurations, the potential measurement between a sensing electrode and a reference electrode may be modeled as being inversely proportional to the distance between a current-carrying electrode and a sensing electrode. For example, the relationship may be modeled as:

$$\varphi_{SEi} = \frac{K}{\|r_{CCE1} - r_{SEi}\|} + C$$

In this example, the parameter K may be used to assess tissue contact. The above equation is just an example. Other models and parameters are contemplated.

As stated above, the model may relate to both the potential differences between one or more sensing electrodes and the distance between a current-carrying electrode and sensing electrodes. For example, FIG. **4** illustrates an example distal end portion **213** including a current-carrying electrode **224** and four sensing electrodes **226**, **234**, **236** and **222**. FIG. **4** also shows lead wires **232a-232e**. It can be appreciated that the sensing electrodes **226**, **234** and **236** may include mini-electrodes while the current-carrying electrode **224** may include a distal ablation tip electrode. Sensing electrodes **226**, **234** and **236** may be disposed on distal tip ablation electrode **224**. Further, a fourth sensing electrode **222** may be positioned proximate electrodes **224**, **226**, **234** and **236**. Referring to FIG. **4**, potential measuring electrode **222** may be a ring electrode. FIG. **4** is just an example. Combinations and configurations of a variety of electrode types may be utilized as either the sensing and/or current-carrying electrodes.

In some instances, the relationship between the above electrodes and potential values may be represented by the following equation:

$$\begin{bmatrix} \varphi_{SE1} \\ \varphi_{SE2} \\ \varphi_{SE3} \\ \varphi_{SE4} \end{bmatrix} = \begin{bmatrix} \frac{1}{\|r_{CCE1} - r_{SE1}\|} & 1 \\ \frac{1}{\|r_{CCE1} - r_{SE2}\|} & 1 \\ \frac{1}{\|r_{CCE1} - r_{SE3}\|} & 1 \\ \frac{1}{\|r_{CCE1} - r_{SE4}\|} & 1 \end{bmatrix} [K \ C]$$

It can be appreciated that the variables

$$\begin{bmatrix} \varphi_{SE1} \\ \varphi_{SE2} \\ \varphi_{SE3} \\ \varphi_{SE4} \end{bmatrix}$$

represent the measured potential difference between the four sensing electrodes and a reference electrode. Additionally, the potential differences may be determined by system **10**. Further, it can be appreciated that $\|r_{CCE1} - r_{SE1}\|$, $\|r_{CCE1} - r_{SE2}\|$, $\|r_{CCE1} - r_{SE3}\|$ and $\|r_{CCE1} - r_{SE4}\|$ represent the absolute value of the distance (in space) between the current-carrying electrode and the four sensing electrodes, respectively. It is

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further understood that these distances may be determined as the position (and distance) for every sensing electrode in relation to the current-carrying electrode is known.

The parameters K and C in the above system of linear equations can be estimated using a number of well-known techniques for optimization or linear regression. For example, least squares can be used to estimate K and C. Other methods are contemplated.

Scaling factor K may be inversely proportional to the conductivity of a given medium. In other words, the scaling factor K will be different for two mediums having different conductivities. For example, the conductivity of blood is greater than that of cardiac tissue, and therefore, the scaling factor K will be lower for blood as compared to cardiac tissue.

Knowing the potential differences and absolute distance values, it may be possible to solve the linear equation set (above) for the scaling factor, K. It should be noted that in order to solve the disclosed linear equation set, sensing electrodes must be located at different distances away from the current injecting electrode. If, for example, the distances were all identical, then the matrix on the right-hand side of the equation would be singular and result in an infinite number of equally valid solutions. Referring to FIG. **4**, it can be seen that sensing electrodes **226**, **234**, **236** and **222** are located at different distances from current injecting electrode **224**.

FIG. **4** illustrates the sensing electrodes **226**, **234**, **236** and **222** positioned longitudinally along the catheter shaft **12**. However, it is contemplated that the sensing electrodes **226**, **234**, **236** and **222** may be positioned in a configuration other than along the longitudinal axis and yet still maintain variable distances between the sensing electrodes and the current-carrying electrode. Additionally, in some instances it may be possible to reduce the number of sensing electrodes to two or three and solve the corresponding linear equation set for scaling factor K. In other instances, it may be desirable to increase the number of sensing electrodes; the parameter K can still be estimated using well-known techniques such as least squares.

It can be appreciated from the above discussion that it may be possible to utilize known variables to solve the disclosed linear equation for the scaling factor K. Therefore, system **10** may determine and compare different scaling factor values as the distal end portion **13** of catheter **12** is moved between different mediums (e.g. blood, tissue).

FIGS. **8a-8c** illustrates distal end portion **213** positioned within a variety of mediums. For example, FIG. **8a** shows distal end portion **213** surround entirely by blood. FIG. **8ab** shows distal end portion **213** positioned at a blood/tissue interface. FIG. **8c** shows distal end portion **213** partially embedded within tissue. As stated, the generated scaling factor K corresponding to FIGS. **8a-8c** may be different for each different medium. The difference in the scaling factors may be utilized as a diagnostic indicator of the proximity of distal end portion **213** to tissue.

The following documents are herein incorporated by reference: U.S. Patent Application Pub. US2008/0243214, U.S. Patent Application Pub. US2014/0058375, U.S. Patent Application Pub. US2013/0190747, U.S. Patent Application Pub. US2013/0060245, and U.S. Patent Application Pub. US2009/0171345.

Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments

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having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

We claim:

1. An electrophysiology medical device, comprising:
a catheter shaft including a distal end portion;
a sensing assembly located on the distal end portion, the sensing assembly having three or more terminals;
wherein the sensing assembly includes one or more current-carrying electrodes and more than one sensing electrodes, wherein a first sensing electrode of the more than one sensing electrodes is spaced apart from the one or more current-carrying electrodes by a first distance, wherein a second sensing electrode of the more than one sensing electrodes is spaced apart from the one or more current-carrying electrodes by a second distance, wherein the first distance is different than the second distance;
wherein at least one of the one or more current-carrying electrodes and the one or more sensing electrodes includes one or more mini-electrodes and one or more non-mini electrodes;
wherein at least one of the one or more mini-electrodes is disposed on at least one of the one or more non-mini electrodes; and
a controller coupled to the sensing assembly, the controller configured to
determine a first potential measurement for the first sensing electrode and a second potential measurement for the second sensing electrode, the first potential measurement being inversely proportional to the first distance and the second potential measurement being inversely proportional to the second distance,
determine a scaling factor based on the first distance, the second distance, the first potential measurement, and the second potential measurement, and determine the conductivity of a medium contacting the sensing assembly based on the scaling factor.
2. The medical device of claim 1, wherein the three or more terminals includes four terminals.
3. The medical device of claim 1, wherein one or more of the three or more terminals are disposed along the distal end portion of the catheter shaft.
4. The medical device of claim 1, wherein one or more of the three or more terminals are disposed along a device separate from the catheter shaft.
5. The medical device of claim 1, wherein the one or more current-carrying electrodes includes at least one mini-electrode of the one or more mini-electrodes.
6. The medical device of claim 1, wherein the one or more sensing electrodes includes one mini-electrode of the one or more mini-electrodes.
7. The medical device of claim 1, wherein the one or more current-carrying electrodes includes a mini-electrode of the one or more mini-electrodes and the one or more sensing electrodes includes two mini-electrodes of the one or more mini-electrodes.
8. The medical device of claim 1, wherein the one or more current-carrying electrodes includes two mini-electrodes of the one or more mini-electrodes and the one or more sensing electrodes includes a mini-electrode of the one or more mini-electrodes.
9. The medical device of claim 1, wherein the one or more current-carrying electrodes includes two mini-electrodes of

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the one or more mini-electrodes and the one or more sensing electrodes includes two mini-electrodes of the one or more mini-electrodes.

10. The medical device of claim 1, wherein the one or more current-carrying electrodes or the one or more sensing electrodes includes an ablation electrode.

11. The medical device of claim 1, wherein the one or more current-carrying electrodes includes an ablation electrode and wherein the one or more sensing electrodes includes an electrode disposed on the ablation electrode.

12. The medical device of claim 1, wherein the one or more sensing electrodes includes an ablation electrode and wherein the one or more current-carrying electrodes includes an electrode disposed on the ablation electrode.

13. The medical device of claim 1, wherein the one or more current-carrying electrodes or the one or more sensing electrodes includes a ring electrode.

14. The medical device of claim 1, wherein the one or more current-carrying electrodes includes an ablation electrode and a ring electrode, and wherein the one or more sensing electrodes includes at least one mini-electrode of the one or more mini-electrodes.

15. The medical device of claim 1, wherein the one or more current-carrying electrodes includes at least one mini-electrode of the one or more mini-electrodes, and wherein the one or more sensing electrodes includes an ablation electrode and a ring electrode.

16. The medical device of claim 1, wherein the one or more current-carrying electrodes includes an ablation electrode and a mini-electrode of the one or more mini-electrodes and wherein the one or more sensing electrodes includes a ring electrode and a mini-electrode of the one or more mini-electrodes.

17. The medical device of claim 1, wherein the one or more current-injecting electrodes includes a ring electrode and a mini-electrode of the one or more mini-electrodes and wherein the one or more sensing electrodes includes an ablation electrode and a mini-electrode of the one or more mini-electrodes.

18. An electrophysiology medical device, comprising:
a catheter shaft including a distal end portion, wherein the distal end portion includes a plurality of electrodes;
wherein the plurality of electrodes includes at least one current-carrying electrode, a first sensing electrode and a second sensing electrode;

wherein at least one of the plurality of electrodes is a mini-electrode and at least one of the plurality of electrodes is a non-mini electrode, wherein one or more of the at least one mini-electrode is disposed on one or more of the at least one non-mini electrode;

wherein the first sensing electrode is spaced from the at least one current-carrying electrode by a first distance; wherein the second sensing electrode is spaced from the at least one current-carrying electrode by a second distance;

wherein the first distance is different from the second distance; and

a controller coupled to the plurality of electrodes, the controller configured to:

determine a first potential measurement for the first sensing electrode and a second potential measurement for the second sensing electrode, the first potential measurement being inversely proportional to the first distance and the second potential measurement being inversely proportional to the second distance,

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determine a scaling factor based on the first distance, the second distance, the first potential measurement, and the second potential measurement, and determine the conductivity of a medium contacting the sensing assembly based on the scaling factor.

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19. The medical device of claim **18**, further comprising: wherein the at least one current-carrying electrode and the first and second sensing electrodes are arranged in at least one four-terminal sensing configuration.

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