



US007672718B2

(12) **United States Patent**
Stahmann et al.

(10) **Patent No.:** US 7,672,718 B2
(45) **Date of Patent:** *Mar. 2, 2010

(54) **THORACIC IMPEDANCE DETECTION WITH BLOOD RESISTIVITY COMPENSATION**

(75) Inventors: **Jeffrey E. Stahmann**, Ramsey, MN (US); **John D. Hatlestad**, Maplewood, MN (US); **Boyce Moon**, Ham Lake, MN (US)

(73) Assignee: **Cardiac Pacemakers, Inc.**, St. Paul, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: 12/139,948

(22) Filed: Jun. 16, 2008

(65) **Prior Publication Data**

US 2008/0249433 A1 Oct. 9, 2008

Related U.S. Application Data

(63) Continuation of application No. 10/921,503, filed on Aug. 19, 2004, now Pat. No. 7,387,610.

(51) **Int. Cl.**
A61B 5/00 (2006.01)

(52) **U.S. Cl.** 600/547

(58) **Field of Classification Search** None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,340,867 A 9/1967 Kubicek et al.

3,608,542 A 9/1971 Pacela et al.
3,871,359 A 3/1975 Pacela
4,003,379 A 1/1977 Ellinwood, Jr.
4,059,169 A 11/1977 Hagen

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0348271 12/1989

(Continued)

OTHER PUBLICATIONS

"U.S. Appl. No. 10/921,503, Amendment and Response filed Oct. 12, 2007 to Non-Final Office Action mailed Jul. 13, 2007", 21 pgs.

(Continued)

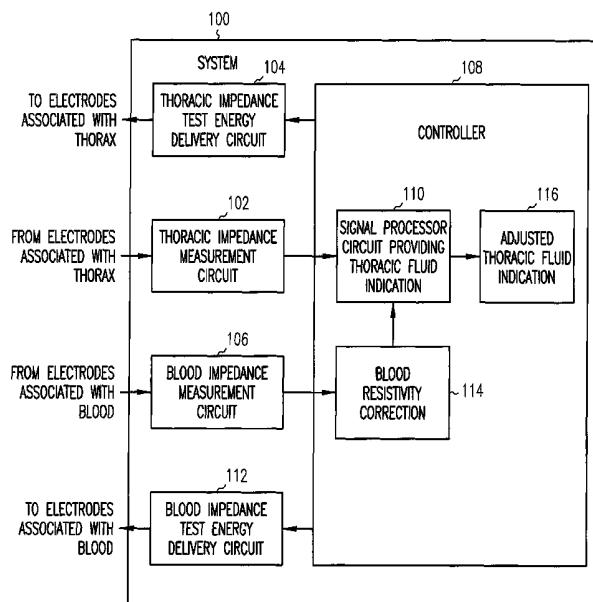
Primary Examiner—Robert L Nasser

(74) *Attorney, Agent, or Firm*—Schwegman, Lundberg & Woessner, P.A.

(57) **ABSTRACT**

This document discusses, among other things, a cardiac rhythm management device or other implantable medical device that uses thoracic impedance to determine how much fluid is present in the thorax, such as for detecting or predicting congestive heart failure, pulmonary edema, pleural effusion, hypotension, or the like. The thoracic fluid amount determined from the thoracic impedance is compensated for changes in blood resistivity, which may result from changes in hematocrit level or other factors. The blood-resistivity-compensated thoracic fluid amount can be stored in the device or transmitted to an external device for storage or display. The blood-resistivity-compensated thoracic fluid amount can also be used to adjust a cardiac pacing, cardiac resynchronization, or other cardiac rhythm management or other therapy to the patient. This document also discusses applications of the devices and methods for predicting or indicating anemia.

20 Claims, 4 Drawing Sheets



US 7,672,718 B2

Page 2

U.S. PATENT DOCUMENTS					
RE30,101 E	9/1979	Kubicek et al.	5,676,686 A	10/1997	Jensen et al.
4,271,192 A	6/1981	Wurtman et al.	5,685,316 A	11/1997	Schookin et al.
4,437,469 A	3/1984	Djordjevich et al.	5,706,829 A	1/1998	Kadri
4,450,527 A	5/1984	Sramek	5,722,999 A	3/1998	Snell
4,470,987 A	9/1984	Wurtman et al.	5,725,561 A	3/1998	Stroebel et al.
4,472,420 A	9/1984	Toth	5,725,562 A	3/1998	Sheldon
4,472,431 A	9/1984	Toth	5,732,710 A	3/1998	Rabinovich et al.
4,559,946 A	12/1985	Mower	5,735,284 A	4/1998	Tsoglin et al.
4,567,892 A	2/1986	Plicchi et al.	5,749,369 A	5/1998	Rabinovich et al.
4,576,183 A	3/1986	Plicchi et al.	5,749,900 A	5/1998	Schroepel et al.
4,651,716 A	3/1987	Forester et al.	5,782,774 A	7/1998	Shmulewitz
4,686,987 A	8/1987	Salo et al.	5,782,879 A	7/1998	Rosborough et al.
4,693,253 A	9/1987	Adams	5,782,884 A	7/1998	Stotts et al.
4,880,005 A	11/1989	Pless et al.	5,788,643 A	8/1998	Feldman
4,884,576 A	12/1989	Alt	5,791,349 A	8/1998	Shmulewitz
4,904,472 A	2/1990	Belardinelli et al.	5,800,464 A	9/1998	Kieval
4,919,136 A	4/1990	Alt	5,824,029 A	10/1998	Weijand et al.
4,980,379 A	12/1990	Belardinelli et al.	5,865,760 A	2/1999	Lidman et al.
4,987,897 A	1/1991	Funke	5,874,420 A	2/1999	Pelleg
5,002,052 A	3/1991	Haluska	5,876,353 A	3/1999	Riff
5,003,976 A	4/1991	Alt	5,882,352 A	3/1999	Duncan et al.
5,025,786 A	6/1991	Siegel	5,913,879 A	6/1999	Ferek-Petric et al.
5,031,629 A	7/1991	DeMarzo	5,919,210 A	7/1999	Lurie et al.
5,036,849 A	8/1991	Hauck et al.	5,957,861 A	9/1999	Combs et al.
5,113,869 A	5/1992	Nappholz et al.	5,957,957 A	9/1999	Sheldon
5,117,825 A	6/1992	Grevious	5,974,340 A	10/1999	Kadhiresan
5,178,154 A	1/1993	Ackmann et al.	5,978,705 A	11/1999	KenKnight et al.
5,179,947 A	1/1993	Meyerson et al.	6,026,324 A	2/2000	Carlson
5,199,428 A	4/1993	Obel et al.	6,035,233 A	3/2000	Schroepel et al.
5,213,098 A	5/1993	Bennett et al.	6,044,297 A	3/2000	Sheldon et al.
5,215,083 A	6/1993	Drane et al.	6,049,735 A	4/2000	Hartley et al.
5,233,985 A	8/1993	Hudrlík	6,075,015 A	6/2000	Sestelo et al.
5,246,008 A	9/1993	Mueller et al.	6,076,015 A	6/2000	Hartley et al.
5,271,395 A	12/1993	Wahlstrand et al.	6,078,834 A	6/2000	Lurie et al.
5,273,034 A	12/1993	Nilsson	6,095,987 A	8/2000	Shmulewitz et al.
5,282,836 A	2/1994	Kreyenhaben et al.	6,104,949 A	8/2000	Pitts Crick et al.
5,282,840 A	2/1994	Hudrlík et al.	6,154,672 A	11/2000	Pendekanti et al.
5,284,136 A	2/1994	Hauck et al.	6,161,038 A	12/2000	Schookin et al.
5,292,343 A	3/1994	Blanchette et al.	6,186,955 B1	2/2001	Baura
5,300,093 A	4/1994	Koestner et al.	6,224,907 B1	5/2001	Davar et al.
5,309,917 A	5/1994	Wang et al.	6,228,033 B1	5/2001	Koobi et al.
5,313,953 A	5/1994	Yomtov et al.	6,266,565 B1	7/2001	Er et al.
5,324,309 A	6/1994	Kallok	6,292,689 B1	9/2001	Wallace et al.
5,324,315 A	6/1994	Grevious	6,298,267 B1	10/2001	Rosborough et al.
5,344,429 A	9/1994	Smits	6,314,322 B1	11/2001	Rosenberg
5,354,317 A	10/1994	Alt	6,317,631 B1	11/2001	Ben-Haim et al.
5,354,319 A	10/1994	Wyborny et al.	6,336,903 B1	1/2002	Bardy
5,355,894 A	10/1994	Sivard	6,409,675 B1	6/2002	Turcott
5,366,485 A	11/1994	Kroll et al.	6,411,844 B1	6/2002	Kroll et al.
5,370,665 A	12/1994	Hudrlík	6,438,408 B1	8/2002	Mulligan et al.
5,391,190 A	2/1995	Pederson et al.	6,473,640 B1	10/2002	Erlebacher
5,404,877 A	4/1995	Nolan et al.	6,511,438 B2	1/2003	Bernstein et al.
5,405,362 A	4/1995	Kramer et al.	6,512,949 B1	1/2003	Combs et al.
5,411,031 A	5/1995	Yomtov	6,560,481 B1	5/2003	Heethaar et al.
5,431,682 A	7/1995	Hedberg	6,561,986 B2	5/2003	Baura et al.
5,441,525 A	8/1995	Shelton et al.	6,574,506 B2	6/2003	Kramer et al.
5,443,073 A	8/1995	Wang et al.	6,595,927 B2	7/2003	Pitts-Crick et al.
5,454,377 A	10/1995	Dzwonczyk et al.	6,600,949 B1	7/2003	Turcott
5,464,434 A	11/1995	Alt	6,602,201 B1	8/2003	Hepp
5,479,369 A	12/1995	Matsumura et al.	6,625,492 B2	9/2003	Florio et al.
5,501,701 A	3/1996	Markowitz et al.	6,636,754 B1	10/2003	Baura et al.
5,505,209 A	4/1996	Reining	6,643,543 B2	11/2003	Takehara et al.
5,507,785 A	4/1996	Deno	6,665,564 B2	12/2003	Lincoln et al.
5,522,860 A	6/1996	Molin et al.	6,678,547 B2	1/2004	Carlson et al.
5,526,808 A	6/1996	Kaminsky	6,714,813 B2	3/2004	Ishigooka et al.
5,534,018 A	7/1996	Wahlstrand et al.	6,748,271 B2	6/2004	Spinelli et al.
5,540,728 A	7/1996	Shelton et al.	6,752,765 B1	6/2004	Jensen et al.
5,562,711 A	10/1996	Yerich et al.	6,811,537 B2	11/2004	Bardy
5,562,712 A	10/1996	Steinhaus et al.	6,829,503 B2	12/2004	Alt
5,626,623 A	5/1997	Kieval et al.	6,907,288 B2	6/2005	Daum
5,642,734 A	7/1997	Ruben et al.	6,908,437 B2	6/2005	Bardy
			6,912,420 B2	6/2005	Scheiner et al.
			7,003,346 B2	2/2006	Singer

US 7,672,718 B2

Page 3

7,149,573	B2	12/2006	Wang	WO	WO-03/020364	A2	3/2003
7,177,681	B2	2/2007	Zhu et al.				
7,191,000	B2	3/2007	Zhu et al.				
7,333,854	B1	2/2008	Brewer et al.				
7,340,296	B2	3/2008	Stahmann et al.				
7,387,610	B2 *	6/2008	Stahmann et al.	600/538		
7,422,560	B2	9/2008	Hatlestad et al.				
2001/0020138	A1	9/2001	Ishigooka et al.				
2002/0115939	A1	8/2002	Mulligan et al.				
2002/0123674	A1	9/2002	Plicchi et al.				
2002/0138014	A1	9/2002	Baura et al.				
2002/0147475	A1	10/2002	Scheiner et al.				
2002/0147476	A1	10/2002	Daum				
2002/0193689	A1	12/2002	Bernstein et al.				
2003/0023279	A1	1/2003	Spinelli et al.				
2003/0028221	A1	2/2003	Zhu et al.				
2003/0055461	A1	3/2003	Girouard et al.				
2003/0074029	A1	4/2003	Deno et al.				
2003/0105496	A1	6/2003	Yu et al.				
2003/0176896	A1	9/2003	Lincoln et al.				
2003/0191503	A1	10/2003	Zhu et al.				
2003/0220580	A1	11/2003	Alt				
2004/0049235	A1	3/2004	Deno et al.				
2004/0073128	A1	4/2004	Hatlestad et al.				
2004/0086864	A1	5/2004	Lo et al.				
2004/0102712	A1	5/2004	Belalcazar et al.				
2004/0116819	A1	6/2004	Alt				
2004/0127807	A1	7/2004	Hatlestad et al.				
2004/0133079	A1	7/2004	Mazar et al.				
2004/0147982	A1	7/2004	Bardy				
2004/0172080	A1	9/2004	Stadler et al.				
2004/0215097	A1 *	10/2004	Wang	600/547			
2004/0215270	A1	10/2004	Ritscher et al.				
2005/0004609	A1	1/2005	Stahmann et al.				
2005/0080460	A1	4/2005	Wang et al.				
2005/0119586	A1	6/2005	Coyle et al.				
2005/0124908	A1	6/2005	Belalcazar et al.				
2005/0137480	A1	6/2005	Alt et al.				
2005/0177062	A1	8/2005	Skrabal et al.				
2005/0283197	A1	12/2005	Daum et al.				
2006/0020295	A1	1/2006	Brockway et al.				
2006/0135886	A1	6/2006	Lippert et al.				
2006/0241512	A1	10/2006	Kwok et al.				
2006/0241513	A1	10/2006	Hatlestad et al.				
2006/0258952	A1	11/2006	Stahmann et al.				
2006/0264776	A1	11/2006	Stahmann et al.				
2006/0293609	A1	12/2006	Stahmann et al.				
2008/0108907	A1	5/2008	Stahmann et al.				
2009/0005697	A1	1/2009	Hatlestad et al.				

FOREIGN PATENT DOCUMENTS

EP	0584388	A1	3/1994	
EP	0620420	A1	10/1994	
EP	0663219	A1	7/1995	
EP	1057498	A2	12/2000	
EP	1078597	A2	2/2001	
EP	0606301	B1	12/2001	
EP	1247487	A1	10/2002	
EP	1275342	A2	1/2003	
EP	0771172	B1	4/2003	
WO	WO-84/00227	A1	1/1984	
WO	WO-93/04627	A1	3/1993	
WO	WO-96/01586	A1	1/1996	
WO	WO-97/37591	A1	10/1997	
WO	WO-97/38628	A1	10/1997	
WO	WO-98/51211	A1	11/1998	
WO	WO-01/41638	A1	6/2001	
WO	WO-02/053026	A2	7/2002	
WO	WO-02/053228	A1	7/2002	

OTHER PUBLICATIONS

- “U.S. Appl. No. 10/921,503, Response and Preliminary Amendment filed Apr. 9, 2007 to Restriction Requirement mailed Mar. 7, 2007”, 19 pgs.
- “U.S. Appl. No. 10/921,503, Restriction Requirement mailed Mar. 7, 2007”, 6 pgs.
- “U.S. Appl. No. 10/921,503, Notice of Allowance mailed Jan. 31, 2008”, 8 pgs.
- “U.S. Appl. No. 10/921,503, Supplemental Amendment and Response filed Oct. 25, 2007 to Office Action mailed Jul. 13, 2007”, 24 pgs.
- “U.S. Appl. No. 10/921,503, Non-Final Office Action mailed Jul. 13, 2007”, 5 pgs.
- “U.S. Appl. No. 11/126,689, Non-Final Office Action mailed Jul. 21, 2008”, 6 pgs.
- “U.S. Appl. No. 11/126,689, Advisory Action Before the Filing of an Appeal Brief mailed Aug. 27, 2007”, 3 pgs.
- “U.S. Appl. No. 11/126,689, Amendment and Response filed Apr. 3, 2007 to Non-Final Office Action mailed Jan. 3, 2007”, 22 pgs.
- “U.S. Appl. No. 11/126,689, Non-Final Office Action mailed Feb. 6, 2009”, 15 pgs.
- “U.S. Appl. No. 11/126,689, Non-Final Office Action mailed Jan. 3, 2007”, 9 pgs.
- “U.S. Appl. No. 11/126,689, Response filed Jan. 22, 2008 to Non-Final Office Action mailed Oct. 19, 2007”, 23 pgs.
- “U.S. Appl. No. 11/126,689, Response filed Oct. 21, 2008 to Non-Final Office Action mailed Jul. 21, 2008”, 13 pgs.
- “U.S. Appl. No. 11/126,689, Response filed Aug. 14, 2007 to Final Office Action mailed Jun. 14, 2007”, 13 pgs.
- “U.S. Appl. No. 11/126,689, Non-Final Office Action mailed Oct. 19, 2007”, 11 pgs.
- “U.S. Appl. No. 11/126,689, Response and Preliminary Amendment filed Oct. 10, 2006 to Restriction Requirement mailed Sep. 8, 2006”, 12 pgs.
- “U.S. Appl. No. 11/126,689, Restriction Requirement mailed Sep. 8, 2006”, 5 pgs.
- “U.S. Appl. No. 11/126,689, Final Office Action mailed Jun. 14, 2007”, 13 pgs.
- “U.S. Appl. No. 11/132,109, Decision from Pre-Appeal Brief Review mailed Aug. 9, 2007”, 2 pgs.
- “U.S. Appl. No. 11/132,109, Final Office Action mailed Jan. 22, 2007”, 13 pgs.
- “U.S. Appl. No. 11/132,109, Non-Final Office Action Mailed Jul. 7, 2006”, 10 pgs.
- “U.S. Appl. No. 11/132,109, Notice of Allowance mailed Oct. 5, 2007”, 10 pgs.
- “U.S. Appl. No. 11/132,109, Pre-Appeal Brief Request for Review filed Apr. 23, 2007”, 5 pgs.
- “U.S. Appl. No. 11/132,109, Response filed Oct. 10, 2006 to Non-Final Office Action mailed Jul. 7, 2006”, 20 pgs.
- “Heart Sounds”, [online]. [retrieved on Dec. 8, 2005]. Retrieved from the Internet: <URL: <http://www.chfpatients.com/faq/s3s4.htm>>, 4 pgs.
- “Medtronic Announces European Release of Innovative InSync Sentry Cardiac Resynchronization Therapy Defibrillator”, [online]. [retrieved on Nov. 23, 2005]. Retrieved from the Internet: <URL: http://www.medtronic.com/newsroom/news_20040614a.html>, (2004), 2 pgs.
- “Medtronic: InSync Sentry 7298: Dual Chamber Implantable Cardioverter Defibrillator with Cardiac Resynchronization Therapy (VVE-DDR) and Opti-Vol™ Fluid Monitoring: Reference Manual”, (2004), 420 pgs.
- Adamicza, A., et al., “Changes in transthoracic electrical impedance during endotoxemia in dogs”, *Acta Physiol Hung.*, 85(4), (1997-98), 291-302.
- Adamicza, A., et al., “Investigation of the thoracic electrical impedance during endotoxemia in dogs”, *Acta Chir Hung.*, 36(1-4), (1997), 1-3.

- Alt, Eckhard, et al., "Control of Pacemaker Rate by Impedance-based Respiratory Minute Ventilation**", *Chest*, 92(2), (Aug. 1987), 247-252.
- Baarends, E. M., et al., "Body-water compartments measured by bio-electrical impedance spectroscopy in patients with chronic obstructive pulmonary disease", *Clinical Nutrition*, 17(1), (Feb. 1998), 15-22.
- Belalcazar, Andres, et al., "Improved lung edema monitoring with coronary vein pacing leads", *Pacing and Clinical Electrophysiology*, 26(4 pt. II), Abstract 18, (Apr. 2003).
- Belalcazar, Andres, et al., "Improved lung edema monitoring with coronary vein pacing leads: a simulation study", *Physiological Measurement*, vol. 25, (2004), 475-487.
- Berman, Irwin R, et al., "Transthoracic electrical impedance s a guide to intravascular overload", *Archives of Surgery*, 102(1), (Jan. 1971), 61-64.
- Bradbury, M. G., et al., "Assessment of the sensitivity of bioimpedance to volume changes in body water", *Pediatr Nephrol.*, 9(3), (Jun. 1995), 337-40.
- Bussmann, W. D., et al., "Effect of Nitroglycerin Sublingual in the Emergency Management of "Classical" Pulmonary Oedema.", (w/ English Abstract), *Deutsche medizinische Wochenschrift*, 102(10), (1946), 9 pgs.
- Campbell, J. H., et al., "Clinical applications of electrical impedance tomography in the monitoring of changes in intrathoracic fluid volumes", *Physiol. Meas.*, vol. 15, (1994), A217-A222.
- Campbell, J. H., et al., "Detection of changes in intrathoracic fluid in man using electrical impedance tomography", *Clinical Science*, vol. 87, (1994), 97-101.
- Charach, Gideon, et al., "Transthoracic monitoring of the impedance of the right lung in patients with cardiogenic pulmonary edema", *Critical Care Medicine*, 29(6), (Jun. 2001), 1137-44.
- Chiolero, R. L., et al., "Assessment of changes in body water by bioimpedance in acutely ill surgical patients.", *Intensive Care Medicine*, 18(6), (1992), 322-6.
- Defaye, P., et al., "Automatic Recognition of Abnormal Respiratory Events During Sleep by a Pacemaker Transthoracic Impedance Sensor", *Journal of Cardiovascular Electrophysiology*, 15(9), (2004), 1034-40.
- Denniston, J. C., et al., "Factors Influencing the measurement of stroke volume by electrical impedance", *Physiology*, 463, (Abstract Only), 1373-1377.
- Denniston, J. C., et al., "Measurement of pleural effusion by electrical impedance.", *Journal of Applied Physiology*, 38(5), (1975), 851-857.
- Ebert, T J, et al., "The use of thoracic impedance for determining thoracic blood volume changes in man", *Aviat Space Environ Med.*, 57(1), (Jan. 1986), 49-53.
- Ellenbogen, Kenneth A, et al., "Rate-adaptive pacing based on impedance-derived minute ventilation", *Clinical Cardiac Pacing*, Philadelphia: Saunders, (1995), 219-233.
- Ellenbogen, Kenneth A, et al., "The Electrode-Tissue Interface and the Foreign Body Response", *Clinical Cardiac Pacing*, Philadelphia: Saunders, (1995), 22-23.
- Fein, Alan, et al., "Evaluation of Transthoracic Electrical Impedance in the Diagnosis of Pulmonary Edema", *Circulation*, 60(5), (1979), 1156-1160.
- Fleischhauer, J., et al., "Electrical resistances of interstitial and microvascular space as determinants of the extracellular electrical field and velocity of propagation in ventricular myocardium", *Circulation*, 92(3), (1995), 587-594.
- Foreman, B, et al., "Intra-thoracic impedance: a surrogate measure of thoracic fluid-fluid accumulation status trial (FAST)", *Journal of Cardiac Failure*, 10(4 Suppl), Abstract 251, (2004), S86.
- Forro, M., et al., "Total body water and ECFV measured using bioelectrical impedance analysis and indicator dilution in horses", *Journal of Applied Physiology*, 89(2), (Aug. 2000), 663-71.
- Frerichs, I., et al., "Electrical impedance tomography in monitoring experimental lung injury", *Intensive Care Med.*, 24(8), (Aug. 1998), 829-36.
- Garland, J. S., et al., "Measurement of extravascular lung water in hemodialysis patients using blood ultrasound velocity and optical density dilution.", *ASAIO Journal* 2002 48(4), (Jul.-Aug. 2002), 398-403.
- Goovaerts, H. G, et al., "Microprocessor-based system for measurement of electrical impedances during haemodialysis and in postoperative care", *Medical & Biological Engineering & Computing*, vol. 26, (Jan. 1988), 75-80.
- Gotshall, R W, et al., "Bioelectric impedance as an index of thoracic fluid.", *Aviation Space and Environmental Medicine*, 70(1), (Jan. 1999), 58-61.
- Grimbert, F., et al., "Pulmonary water and thoracic impedance. Evaluation of a measurement technic", *Annales de l'anesthésiologie Française*, 16 Spec No. 2-3, French, (1975), 157-63.
- Harris, N. D., et al., "Applications of applied potential tomography (APT) in respiratory medicine", *Clinical Physics and Physiological Measurement*, 8 Suppl A, (1987), 155-65.
- Hatlestad, J. D, et al., "Physiological Response to Posture Change", U.S. Appl. No. 11/466,925, filed Aug. 24, 2006, 21 Pages.
- Hatlestad, John D, et al., "Calibration of Impedance Monitoring of Respiratory Volumes Using Thoracic D.C. Impedance", U.S. Appl. No. 11/14,661, Date Mailed Apr. 26, 2005, 31 Pages.
- Hoon, Raghunath Singh, et al., "Changes in Transthoracic electrical impedance at high altitude", *British Heart Journal*, vol. 39, (1977), 61-66.
- Hull, E. T, et al., "The Transthoracic Impedance Method for the Determination of the Degree and Change in Extravascular Water", *Acta Tuberc. Pneumol. Belg.*, 68(4), (1977), 369-377.
- Hull, E. T, et al., "Transthoracic electrical impedance: artifacts associated with electrode movement", *Resuscitation*, 6(2), (1978), 115-124.
- Ishibe, Y., et al., "Transthoracic electrical impedance method for measurement of pulmonary edema in vivo", *Masui*; 27(13), Japanese, (Dec. 1978), 1559-67.
- Joekes, A. M, et al., "Impedance Cardiography—Its value in an intensive care unit", *D) Materiels et techniques/Cardiocirculatory Equipment and Techniques*, Abstract No. 141, 1 Page.
- Keller, Guido, et al., "Monitoring of Pulmonary Fluid Volume and Stroke Volume by Impedance Cardiography in Patients on Hemodialysis", *Chest*, 72(1), (Jul. 1977), 56-62.
- Khan, Mahfooz R, et al., "Quantitative electrical-impedance plethysmography for pulmonary oedema", *Medical & Biological Engineering & Computing*, vol. 15, (Nov. 1977), 627-633.
- Kiesler, T. W., et al., "Impedance cardiography by use of a spot-electrode array to track changes in cardiac output in anesthetized dogs.", *Journal of the American Veterinary Medical Association*, 196(11), (Jun. 1, 1990), 1804-10.
- Koizumi, T., "Changes of transthoracic impedance (zinf0 and deltaz) in newborn infants", *Acta Neonatol. Jpn.*, 14(3), (1978), 335-340.
- Kunst, P. W., et al., "Electrical impedance tomography in the assessment of extravascular lung water in noncardiogenic acute respiratory failure", *Chest*, 116(6), (Dec. 1999), 1695-702.
- Kurimoto, et al., "A Case of Pulmonary Edema in a Horse Treated for Cardiac Ailments", *J. Equine Sci*, vol. 13 No. 1., (2002), 29-34.
- Kusumoto, Fred M, et al., "Medical Progress: Cardiac Pacing", *New England Journal of Medicine*, 334(2), (Jan. 11, 1996), 89-98.
- Larsen, F., et al., "Influence of furosemide and body posture on transthoracic electrical impedance in AMI", *Chest*, 90(5), (733-7), Nov. 1986.
- Laszlo, Z., et al., "Cardiovascular and Hormonal Changes with Different Angles of Head-up Tilt in Men", *Physiol. Res.*, vol. 50, (2001), 71-82.
- Lau, C P, et al., "Rate-responsive pacing with a pacemaker that detects respiratory rate (Biorate): clinical advantages and complications", *Clinical Cardiology*, 11(5), (May 1988), 318-24.
- Lau, C. P., "The range of sensors and algorithms used in rate adaptive cardiac pacing", *Pacing and clinical electrophysiology: PACE*, 15(8), (Aug. 1992), 1177-211.

- Leung, Zoe KC, et al., "Feasibility of an automatic atrial and ventricular threshold determination using transthoracic using impedance", *Pacing and Clinical Electrophysiology*, vol. 19, Part II, Abstract 263, (Apr. 1996), 631.
- Luepker, R. V., et al., "Transthoracic Electrical Impedance: Quantitative Evaluation of a Non-Invasive Measure of Thoracic Fluid Volume", *American Heart Journal*, 85(1), (Jan. 1973), 83-93.
- Mai, J., et al., "Enhanced Rate Response Algorithm for Orthostatic Compensation Pacing", *Pacing Clin Electrophysiol*, 23, Naspe Abstracts, Abstract No. 678, (Apr. 2000), 722.
- McCarty, Richard N, et al., "Assessment of pulmonary edema in acute congestive heart failure with impedance cardiography", *J Am Osteopath Assoc.*, 74(9), (May 1975), 879.
- McNamee, James E, et al., "Peribronchial electrical admittance measures lung edema and congestion in the dog", *Special Communications, Electrical Admittance and Pulmonary Edema*, 337-341.
- Newell, J. C., et al., "Assessment of acute pulmonary edema in dogs by electrical impedance imaging", *IEEE Transactions on Biomedical Engineering*, 43(2), (Feb. 1996).
- Nierman, D. M., et al., "Evaluation of transthoracic bioelectrical impedance analysis in monitoring lung water during diuresis", *Applied Cardiopulmonary Pathophysiology*, 7(1), (1997), 57-62.
- Nierman, David M, "Transthoracic Bioimpedance Can Measure Extravascular Lung Water in Acute Lung Injury I", *Journal of Surgical Research* 65, Article No. 0350, (1996), 101-108.
- Noble, T. J., et al., "Diuretic induced change in lung water assessed by electrical impedance tomography", *Physiol Meas.*, 21(1), (Feb. 2000), 155-63.
- Nukiwa, Toshihiro, et al., "Responses of Serum and Lung Angiotensin-Converting Enzyme Activities in the Early Phase of Pulmonary Damage Induced by Oleic Acid in Dogs", *Am Rev Respir Dis.*, 126(6), (Dec. 1982), 1080-1086.
- Petersen, J. R., et al., "Electrical impedance measured changes in thoracic fluid content during thoracentesis", *Clin Physiol.*, 14(4), (Jul. 1994), 459-66.
- Petersen, M E, et al., "Cardiac pacing for vasovagal syncope: a reasonable therapeutic option?", *Pacing Clin Electrophysiol.*, 20(3 Pt 2), (Mar. 1997), 824-6.
- Platia, Edward V, et al., "Time Course of Transvenous Pacemaker Stimulation Impedance, Capture Threshold, and Electrogram Amplitude", *Pacing Clin Electrophysiol.*, 9(5), (Sep./Oct. 19), 620-625.
- Pomerantz, M, et al., "Transthoracic electrical impedance for the early detection of pulmonary edema", *Surgery*, 66(1), (Jul. 1969), 260-8.
- Raijmakers, E., et al., "Estimation of non-cardiogenic pulmonary oedema using dual-frequency electrical impedance", *Medical & Biological Engineering & Computing*, 36(4), (Jul. 1998), 461-6.
- Raggeneau, J. L, et al., "Monitoring of intracellular and extracellular hydric compartments by body impedance", *Anesth Anal Rean*, vol. 36, (1979), 439-443.
- Ramos, Marcos U, et al., "Transthoracic electric impedance. A clinical guide of pulmonary fluid accumulation in congestive heart failure", *Minnesota Medicine*, 58(9), (Sep. 1975), 671-676.
- Rosborough, John P, et al., "Electrical Therapy for Pulseless Electrical Activity", *NASPE*, 23(4), Part II, Abstract, (Apr. 2000), 591.
- Saunders, Charles E, "The Use of Transthoracic Electrical Bioimpedance in Assessing Thoracic Fluid Status in Emergency Department Patients", *American Journal of Emergency Medicine*, 6(4), (Jul. 1988), 337-340.
- Schuster, C. J, et al., "Application of Impedance Cardiography in Critical Care Medicine", *Resuscitation*, vol. 11, (1984), 255-274.
- Schwartzman, David, et al., "Serial Defibrillation Lead Impedance in Patients with Epicardial and Nonthoracotomy Lead Systems", *Journal of Cardiovascular Electrophysiology*, 7(8), (Aug. 1996), 697-703.
- Segev, G., et al., "B-Type Natriuretic Peptide: A Novel Clinical Tool for Diagnosis and Management of Heart Failure", *Hospital Physician*, .., (Sep. 2003), 19-24.
- Shochat, M., et al., "Internal thoracic impedance monitoring: a new prospect in acute heart failure", *European Heart Journal*, 25(Supp), (Aug.-Sep. 2004), p. 72-72.
- Shoemaker, William C, et al., "Multicenter trial of a new thoracic electrical bioimpedance device for cardiac output estimation", *Critical Care Medicine*, 22(12), (Dec. 1994), 1907-1912.
- Smith, R. M., et al., "Canine thoracic electrical impedance with changes in pulmonary gas and blood volumes.", *Journal of Applied Physiology*, 53(6), (Dec. 1982), 1608-13.
- Spinale, F. G., et al., "Noninvasive estimation of extravascular lung water using bioimpedance.", *The Journal of Surgical Research*, 47(6), (Dec. 1989), 535-40.
- Spinelli, J. C., "Method and System for Treatment of Neurocardiogenic Syncore", U.S. Appl. No. 10/862,831, filed Jun. 7, 2004, 15 pages.
- Sra, J S, et al., "Cardiac pacing during neurocardiogenic (vasovagal) syncope", *J Cardiovasc Electrophysiol.*, 6(9), (Sep. 1995), 751-60.
- Stadler, R., et al., "Automated detection of decreases in intrathoracic impedance to predict CHF hospitalization", *Abstract 263*, 26(4 pt II), Abstract 16, (Apr. 2003), 932.
- Stahmann, Jeffrey E, et al., "Detection of Pleural Effusion Using Transthoracic Impedance", U.S. Appl. No. 11/132,109, filed May 18, 2005, 47 Pages.
- Staub, N. C., "The measurement of lung water content.", *The Journal of Microwave Power*, 18(3), (Sep. 1983), 259-63.
- Tang, W., "Assessment of total body water using bioelectrical impedance analysis in neonates receiving intensive care", *Arch Dis Child Fetal Neonatal Ed.*, 77(2), (Sep. 1997), F123-6.
- Tempel, G., et al., "Transthoracic electrical impedance in anaesthesia and intensive care.", *Resuscitation*, 6(2), (1978), 97-105.
- Thakur, Ranjan K, et al., "Pericardial Effusion Increases Defibrillation Energy Requirement", *Pacing Clin Electrophysiol.*, 16(6), (Jun. 1993), 1227-1230.
- Vainshtein, G. B, et al., "The Functioning of the Cerebral Circulation System in Hyperthermia in Rabbits", *Fiziol Zh SSSR Im I M Sechenova*, 75(11), (Nov. 1989), 1608-1614.
- Van De Water, Joseph M, et al., "Monitoring the Chest with Impedance", *Chest*, 64(5), (Nov. 1973), 597-603.
- Viirila, H, "Controlled growth of antimony-doped tin dioxide thin films by atomic layer epitaxy", *Thin Solid Films*, 251, (Nov. 1994), 127-135.
- Viirila, H, et al., "Controlled growth of tin dioxide thin films by atomic layer epitaxy", *Thin Solid Films*, 249(2), (Sep. 1994), 144-149.
- Visokay, M R, "Application of HfSiON as a gate dielectric material", *Applied Physics Letters*, 80(17), (Apr. 2002), 3183-3185.
- Wang, L., et al., "Impedance based prediction of CHF admission precedes symptoms in heart failure patients", *Heart rhythm : the official journal of the Heart Rhythm Society*, 1(Suppl 1), Abstract 679, (2004), S213.
- Wang, L., et al., "Prediction of CHF hospitalization by ambulatory intrathoracic impedance measurement in CHF patients is feasible using pacemaker or ICD lead systems", *Pacing and Clinical Electrophysiology*, 26(4 pt. II), Abstract 123, (Apr. 2003), 959.
- Wang, Li, et al., "Multiple Sources of the Impedance Cardiogram Based on 3-D Finite Difference Human Thorax Models", *IEEE Transactions on Biomedical Engineering*, 42(2), (Feb. 1995), 141-148.
- Wuerz, Richard C, et al., "Effects of prehospital medications on mortality and length of stay in congestive heart failure", *Annals of Emergency Medicine*, 21(6), (Jun. 1992), 669-74.
- Yu, C., et al., "Changes in device based thoracic impedance in decompensating congestive heart failure", *Circulation*, 104(17 supplement), Abstract 1994, (2001), II-419.
- Yu, C. M., et al., "Correlation of device-based intra-thoracic impedance and patient fluid status during intravenous diuretic therapy in acute CHF", *European Heart Journal*, 23(Abstract Supplement), (2002), 158.
- Yu, C., et al., "Device-based intra-thoracic impedance correlates with fluid status and provides automated prediction of CHF hospitalization", *Journal of Cardiac Failure*, 10(4 Suppl), Abstract 354, (2004), S113.
- Yu, C., et al., "Early warning of CHF hospitalization by intra-thoracic impedance measurement in CHF patients with pacemakers", *Pacing and Clinical Electrophysiology: PACE*, 24(4 pt II), Abstract 19, (2002), 527.

Yu, C. M., et al., "Impedance measurements from implanted devices provide automated prediction of CHF hospitalization", *European Heart Journal*, 25(Supp), (Aug.-Sep. 2004), P27-27.

Yu, C. M., et al., "Intrathoracic impedance: A surrogate measure of fluid retention and predictor of hospitalization in patients with heart failure", *Journal of the American College Of Cardiology*, 41(6 Supplement A), Abstract 1206-70, 2003, 210A.

Yu, Cheuk-Man, et al., "Early warning of CHF hospitalization by intra-thoracic impedance measurement in CHF patients with pace-

makers", *Pacing and Clinical Electrophysiology*, 24, (Apr. 2001), 19.

Zellner, J. L., et al., "Bioimpedance: a novel method for the determination of extravascular lung water", *The Journal of Surgical Research*, 48(5), (May 1990), 454-9.

Zima, E., "Intracardiac impedance in biventricular electrode configuration for left ventricular volume monitoring", *European Heart Journal*, 25(Supp), (Aug.-Sep. 2004), p. 165-165.

* cited by examiner

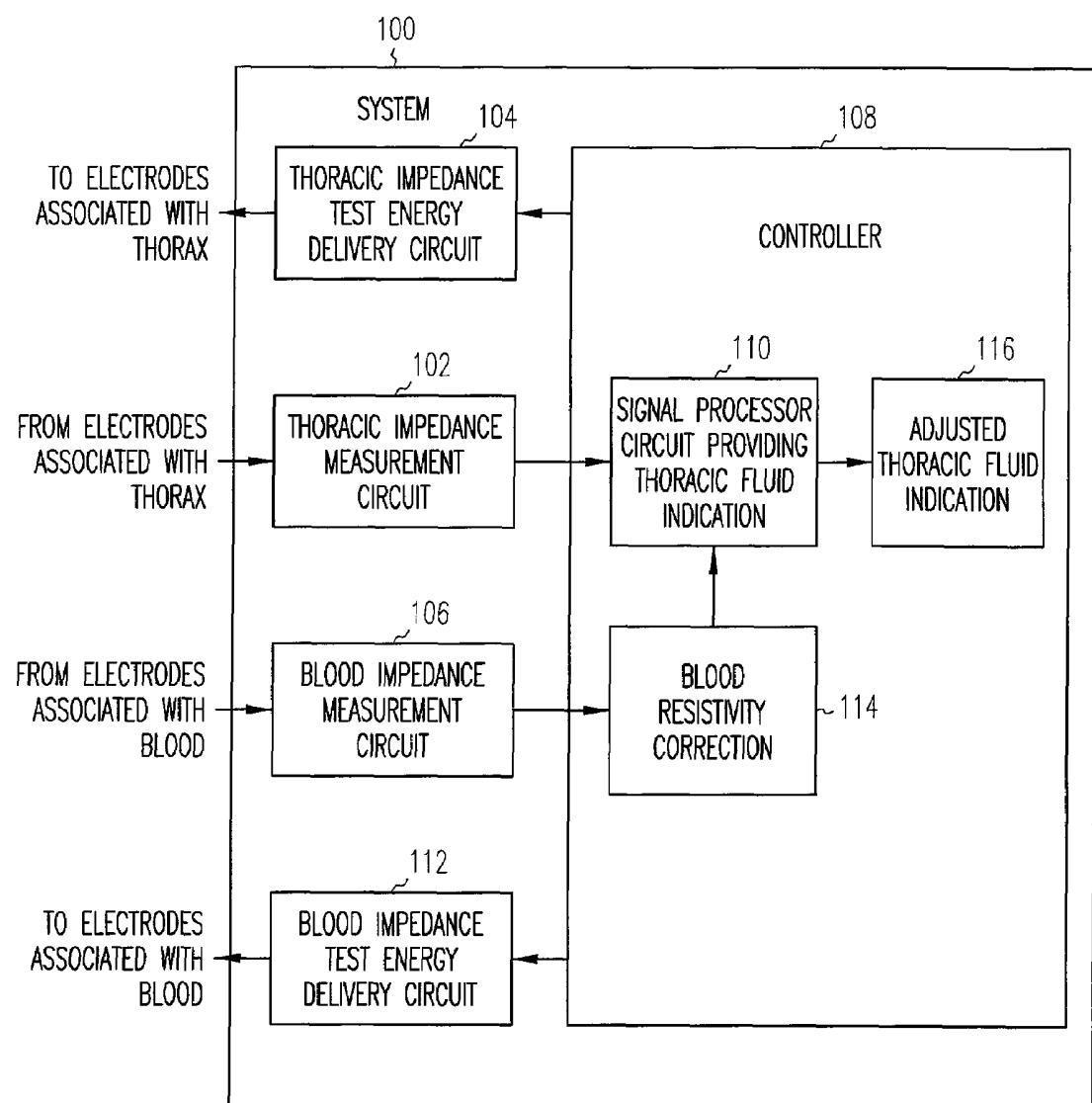


FIG. 1

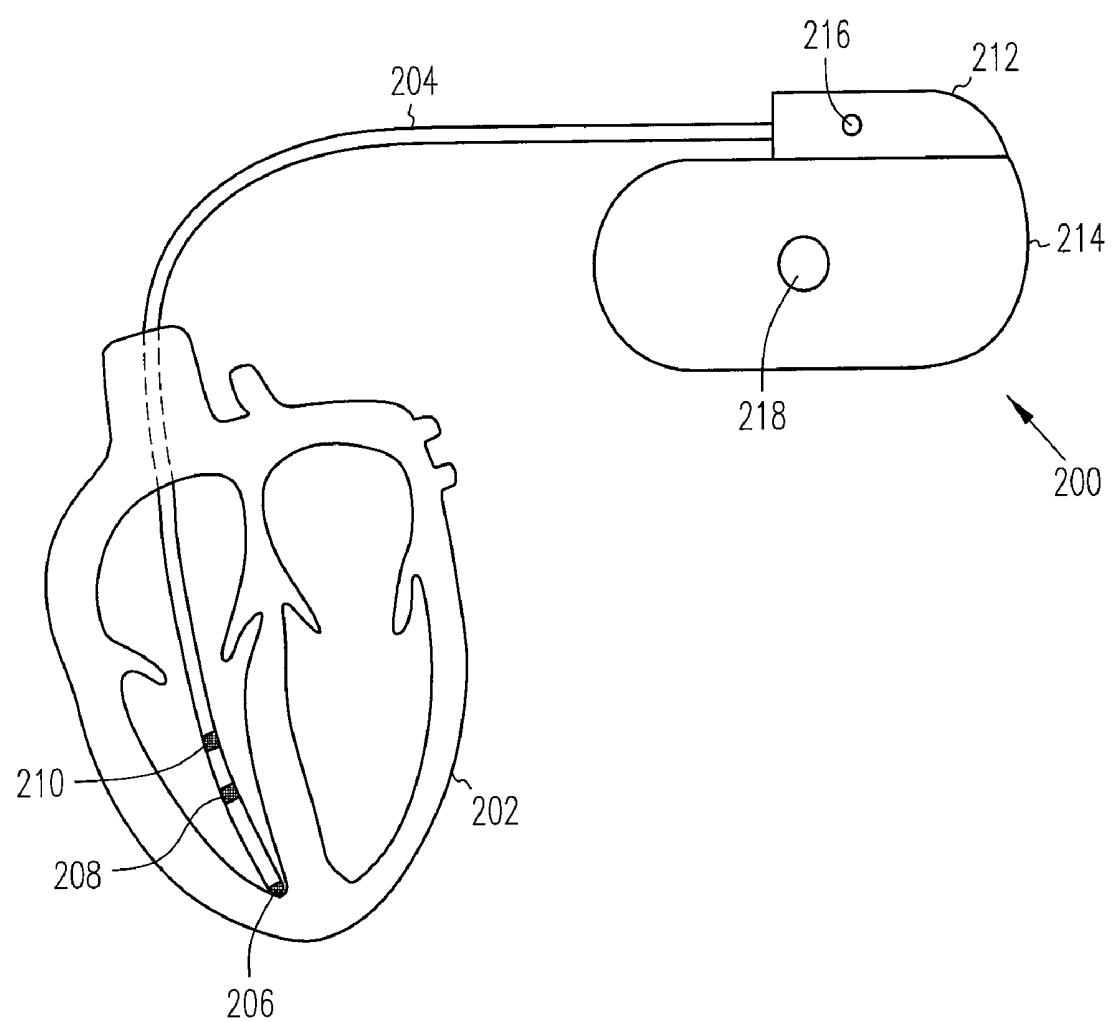


FIG. 2

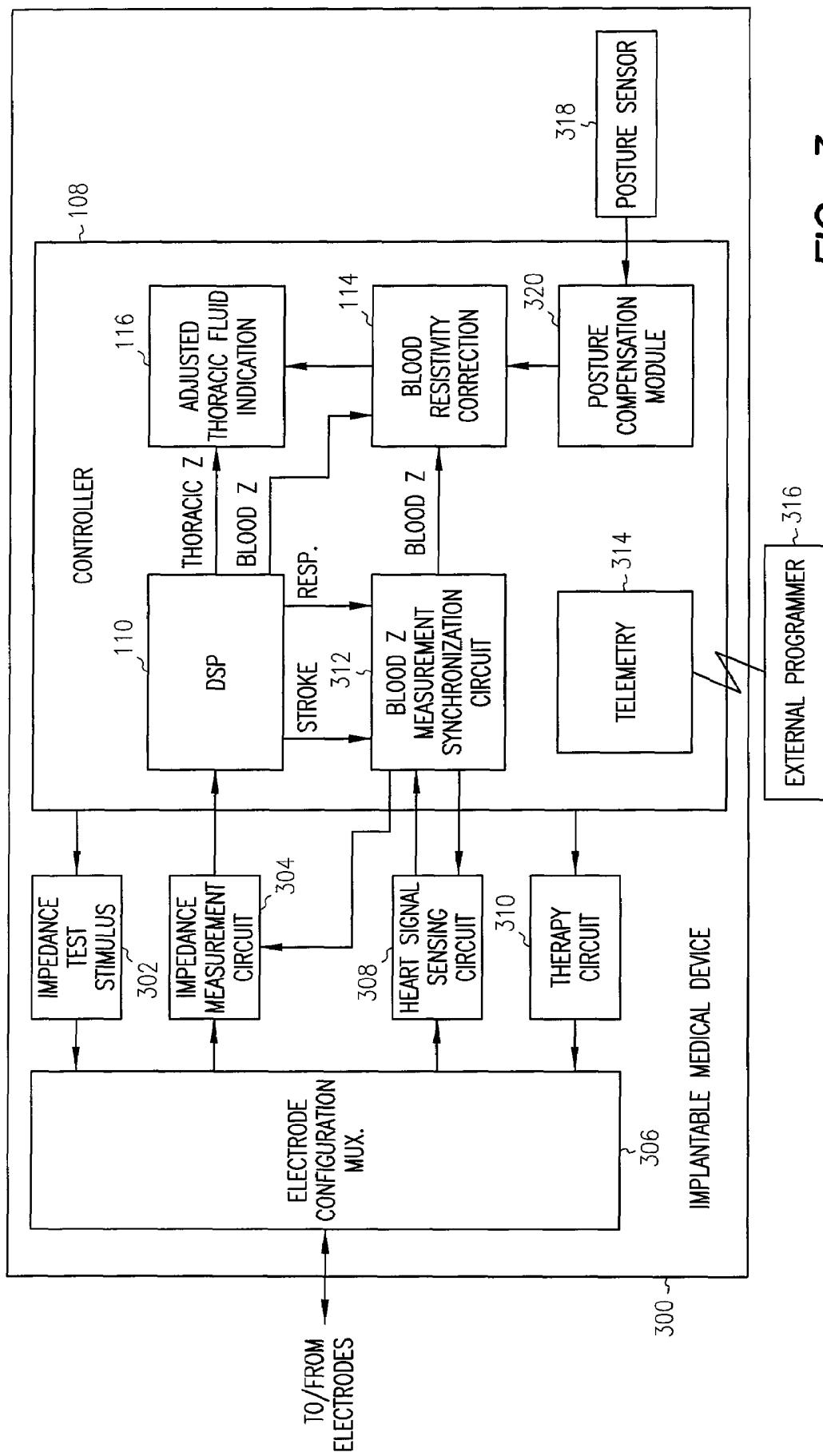


FIG. 3

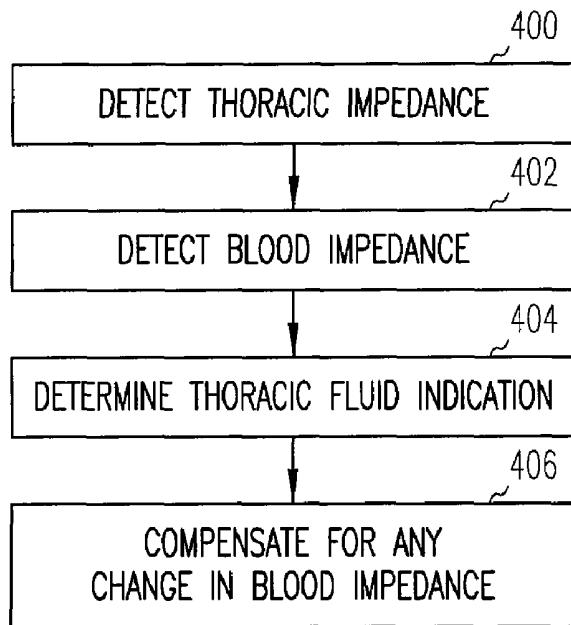


FIG. 4

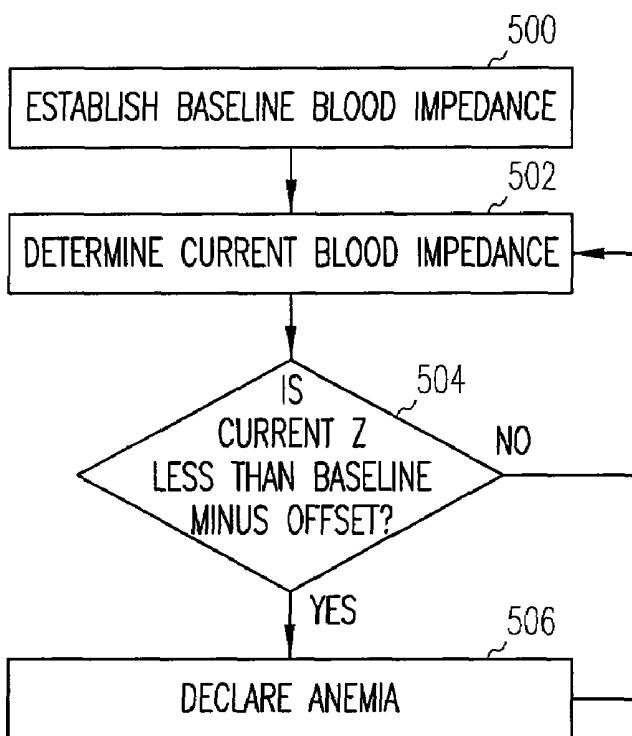


FIG. 5

THORACIC IMPEDANCE DETECTION WITH BLOOD RESISTIVITY COMPENSATION

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 10/921,503, filed Aug. 19, 2004, now U.S. Pat. No. 7,387,610, the specification of which is herein incorporated by reference.

TECHNICAL FIELD

This document pertains generally to implantable medical devices and more particularly, but not by way of limitation, to congestive heart failure (CHF) thoracic fluid detection and other thoracic impedance systems, devices, or methods that compensate or correct for changes in blood resistivity.

BACKGROUND

Variations in how much fluid is present in a person's thorax can take various forms and can have different causes. Eating salty foods can result in retaining excessive fluid in the thorax and elsewhere. Posture changes can also affect the amount of thoracic fluid. For example, moving from supine to standing can shift intravascular fluid away from the thorax toward the lower extremities.

Another example is pulmonary edema, which results in buildup of extravascular fluid in the lungs. In pulmonary edema, fluid accumulates in extracellular spaces, such as the spaces between lung tissue cells. One cause of pulmonary edema is congestive heart failure (CHF), which is also sometimes referred to as "chronic heart failure," or as "heart failure." CHF can be conceptualized as an enlarged weakened portion of heart muscle. The impaired heart muscle results in poor cardiac output of blood. As a result of such poor blood circulation, blood tends to pool in blood vessels in the lungs. This intravascular fluid buildup, in turn, results in the extravascular fluid buildup mentioned above. In sum, pulmonary edema can be one important condition associated with CHF.

Yet another example of thoracic fluid accumulation is pleural effusion, which is the buildup of extravascular fluid in the space between the lungs and the rib cage. Pleural effusion can also result from CHF because, as discussed above, intravascular fluid buildup can result in the extravascular interstitial fluid buildup. The extravascular fluid buildup of pulmonary edema can, in turn, result in the extravascular fluid buildup of pleural effusion.

CHF may also activate several physiological compensatory mechanisms. Such compensatory mechanisms are aimed at correcting the reduced cardiac output. For example, the heart muscle may stretch to increase its contractile power. Heart muscle mass may also increase. This is referred to as "hypertrophy." The ventricle may also change its shape as another compensatory response. In another example, a neuro-endocrine response may provide an adrenergic increase in heart rate and contraction force. The Renin-Angiotensin-Al-dosterone-System (RAAS) may be activated to induce vasoconstriction, fluid retention, and redistribution of blood flow. Although the neuro-endocrine response is compensatory, it may overload the cardiovascular system. This may result in myocardial damage, and may exacerbate CHF.

Diagnosing CHF may involve physical examination, electrocardiogram (ECG), blood tests, chest radiography, or echocardiography. Managing a CHF patient is challenging.

CHF may require potent drugs. Moreover, treatment may be thwarted by the compensatory mechanisms, which may recompensate for the presence of the medical treatment. Therefore, treating CHF involves a delicate balance to properly manage the patient's hemodynamic status in a state of proper compensation to avoid further degeneration.

However, this delicate balance between compensation and effective CHF treatment is easily upset, even by seemingly benign factors, such as common medication (e.g., aspirin), physiological factors, excitement, or gradual progression of the disease. This may plunge the patient into a decompensation crisis, which requires immediate corrective action so as to prevent the deterioration of the patient's condition which, if left unchecked, can lead to death. In sum, accurately monitoring the symptoms of CHF, such as thoracic fluid accumulation, is very useful for avoiding such a decompensation crisis and properly managing the CHF patient in a state of relative well-being.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are not necessarily drawn to scale, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. 1 is a block diagram illustrating generally one example of a system that provides a thoracic fluid amount indication that is adjusted to compensate for a change in blood resistivity, if any.

FIG. 2 is a schematic illustration of one example in which portions of the system are implemented in an implantable cardiac rhythm management (CRM) or other implantable medical device (IMD).

FIG. 3 is a block diagram illustrating generally another example in which portions of the system are implemented in an implantable CRM or other IMD.

FIG. 4 is a flow chart illustrating generally one example of a method of providing a thoracic fluid amount indication that is compensated for any changes in blood resistivity.

FIG. 5 is a flow chart illustrating generally one example of a method of detecting anemia using a blood impedance measurement performed by an implantable medical device.

DETAILED DESCRIPTION

The following detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments, which are also referred to herein as "examples," are described in enough detail to enable those skilled in the art to practice the invention. The embodiments may be combined, other embodiments may be utilized, or structural, logical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one. In this document, the term "or" is used to refer to a nonexclusive or, unless otherwise indicated. Furthermore, all publications, patents, and patent documents referred to in this document are incorporated by reference herein in their

entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

In this document, the term intravascular includes the term intracardiac.

In this document, the term cardiovascular includes an association with either the heart or a blood vessel.

In this document, the term "thorax" refers to a human subject's body other than the subject's head, arms, and legs.

FIG. 1 is a block diagram illustrating generally one example of a system 100 that provides an indication of the amount of fluid in the thorax ("thoracic fluid indication") that is adjusted to compensate for a change in blood resistivity, if any. In this example, the system 100 includes a thoracic impedance measurement circuit 102. The thoracic impedance measurement circuit 102 receives at least one electrical signal from electrodes associated with a patient's thorax. This electrical signal is typically received in response to a test energy applied to the thorax, such as by a thoracic impedance test energy delivery circuit 104.

One illustrative example of some electrode configurations and circuits for performing thoracic impedance measurements is described in Hartley et al. U.S. Pat. No. 6,076,015 entitled RATE ADAPTIVE CARDIAC RHYTHM MANAGEMENT DEVICE USING TRANSTHORACIC IMPEDANCE, which is assigned to Cardiac Pacemakers, Inc., and which is incorporated herein by reference in its entirety, including its description of performing thoracic impedance measurements. The Hartley et al. U.S. Pat. No. 6,076,015 uses thoracic impedance to obtain a respiration signal. By contrast, the present patent application uses thoracic impedance to obtain a thoracic fluid status signal. Therefore, the signal of interest in the present patent application would be deemed noise in the Hartley et al. U.S. Pat. No. 6,076,015, and vice-versa. However, both thoracic fluid status and respiration are obtainable using the thoracic impedance detection techniques described in the Hartley et al. U.S. Pat. No. 6,076,015. The present thoracic fluid status signal of interest is obtained from a lower frequency (i.e., a "near-DC") portion of the thoracic impedance signal rather than the frequencies of the respiration signal described in the Hartley et al. U.S. Pat. No. 6,076,015. In this document, the "near-DC" component of the thoracic impedance signal refers to the frequencies below which respiration and cardiac contractions significantly influence the thoracic impedance signal. This near-DC component of the thoracic impedance signal, therefore, typically refers to signal frequencies below a cutoff frequency having a value of about 0.1 Hz, such as at signal frequencies between about 5×10^{-7} Hz and 0.05 Hz, because the cardiac stroke and respiration components of the thoracic impedance signal lie at higher frequencies. Fluid accumulation in the thorax corresponds to a decrease in the near-DC thoracic impedance. Conversely, fluid depletion in the thorax corresponds to an increase in the near-DC thoracic impedance. As discussed above, fluid accumulation may result from, among other things, pulmonary edema or pleural effusion, both of which may result from CHF.

In the example of FIG. 1, the system 100 also includes a controller 108. The controller 108 is typically a microprocessor or any other circuit that is capable of sequencing through various control states such as, for example, by using a digital microprocessor having executable instructions stored in an associated instruction memory circuit, a microsequencer, or a state machine. In this example, the controller 108 includes a

digital signal processor (DSP) circuit 110. The digital signal processor circuit 110 performs any digital filtering or other signal processing needed to extract from the thoracic impedance signal a near-DC desired thoracic fluid amount signal. The digital signal processor circuit 110, therefore, may implement one or more filter circuits, and such filter circuits may be implemented as a sequence of executable instructions, rather than by dedicated filtering hardware.

However, the present inventors have recognized that the near-DC thoracic impedance signal is typically also affected by confounding factors other than the amount of fluid present in the thorax. One such confounding factor is any change in blood resistivity. Blood resistivity changes as a function of hematocrit in the blood. The hematocrit (Ht) or packed cell volume (PCV) is the proportion of blood that is occupied by red blood cells. It is typically between 0.35 and 0.52, and is slightly higher on average in males than in females. For example, when a patient is dehydrated, there will be less fluid in the patient's blood. Therefore, the patient's hematocrit level will increase, that is, the patient's blood will include a higher percentage of other components, such as insulative red blood cells. This will increase the blood resistivity, which, in turn, will affect the thoracic impedance signal even through it is not necessarily associated with the extravascular fluid accumulation of pulmonary edema or pleural effusion. Other factors that are believed to possibly influence blood resistivity include the patient's electrolyte level, certain medications in the blood, proteins in the blood, or blood gas concentrations.

As an illustrative example, the above change in hematocrit percentage from 35% to 52% may correspond to a change in resistivity from about 140 $\Omega\text{-cm}$ to about 200 $\Omega\text{-cm}$. Such changes in blood resistivity will influence the near-DC thoracic impedance measurement. This will confound an extravascular thoracic fluid amount determination using the near-DC thoracic impedance measurement, unless the extravascular thoracic fluid amount determination is corrected for such variations in blood resistivity, if any. Measurement of variations in blood resistivity is typically affected by the frequency of the excitation signal that are used. At higher excitation frequencies, blood cells typically become more resistive.

Accordingly, the system in FIG. 1 illustrates a blood resistivity measurement circuit 106. The blood impedance measurement circuit 106 receives a blood impedance measurement from electrodes that are associated with blood (and preferably blood in the thorax) such as in response to a delivery of test energy by a blood impedance test energy delivery circuit 112. In one example, the blood impedance measurement circuit 106 and the blood impedance test energy delivery circuit 112 are configured similar to the thoracic impedance measurement circuit 102 and the thoracic impedance test energy delivery circuit 104, respectively, as discussed above, except for being connected to different electrodes. Using the blood impedance measurement, the controller 108 executes a sequence of instructions to compute a blood resistivity correction 114. The blood resistivity correction 114 is applied to the thoracic fluid indication that is output by the digital signal processor circuit 110. This yields an adjusted thoracic fluid amount indication 116.

In FIG. 1, the thoracic impedance test energy delivery circuit 104 is illustrated separately from the blood impedance test energy delivery circuit 112 to assist the reader's conceptualization. In practice, these circuits, or portions thereof, may be combined. The combined circuit may be coupled to different electrodes for delivering the thoracic impedance test energy than for delivering the blood impedance test energy. Similarly, in FIG. 1, the thoracic impedance measurement

circuit 102 is illustrated separately from the blood impedance test energy delivery circuit 112 to assist the reader's conceptualization. In practice, these circuits, or portions thereof, may be combined. The combined circuit may be coupled to different electrodes for measuring the responsive voltages for the thoracic and blood impedance measurements, as discussed below.

FIG. 2 is a schematic illustration of one example in which portions of the system 100 are implemented in an implantable cardiac rhythm management (CRM) or other implantable medical device (IMD) 200. In this example, the IMD 200 is coupled to a heart 202 using at least one leadwire, such as a multielectrode leadwire 204. In this example, the leadwire 204 includes a tip electrode 206, a distal ring electrode 208, and a proximal ring electrode 210, each of which is disposed in the right ventricle of the heart 202. In this example, each of the tip electrode 206, the distal ring electrode 208, and the proximal ring electrode 210 is independently electrically connected to a corresponding separate electrically conductive terminal within an insulating header 212. The header 212 is affixed to a housing 214 carrying electronic components of the IMD 200. In this example, the header 212 includes a header electrode 216, and the housing 214 includes a housing electrode 218.

In one example, thoracic impedance is sensed by delivering a test current between: (1) at least one of the ring electrodes 208 or 210; and (2) the housing electrode 218, and a resulting responsive voltage is measured across the tip electrode 206 and the header electrode 216. Because the IMD 200 is typically pectorally implanted at some distance away from the heart 202, this electrode configuration injects the test current over a substantial portion (but typically not the entire portion) of the patient's thorax, such that when the resulting voltage measurement is divided by the test current magnitude, it yields an indication of thoracic impedance. Using different electrodes for delivering the current and for measuring the responsive voltage reduces the component of the measured impedance signal that results from ohmic losses in the leadwires to the test current delivery electrodes. While such a "four-point" probe is useful, it is not required. In other examples, a "three-point probe" (having three electrodes, with one electrode used for both test current delivery and responsive voltage measurement), or a "two-point probe" (having two electrodes, each electrode used for both test current delivery and responsive voltage measurement) are used. Moreover, other electrode combinations could alternatively be used to implement a four-point probe. The above four-point probe description provides an illustrative example of one suitable four-point probe configuration.

In one example, blood impedance is sensed by delivering a test current between: (1) one of the distal ring electrode 208 or the proximal ring electrode 210; and (2) the housing electrode 218. A resulting responsive voltage is measured between: (1) the other of the distal ring electrode 208 or the proximal ring electrode 210; and (2) the tip electrode 206. In this example, although the test current is injected across a substantial portion of the patient's thorax, as discussed above, the responsive voltage signal of interest is measured across electrodes within the same chamber of the patient's heart (or, alternatively, within the same blood vessel). Therefore, when the responsive voltage measurement is divided by the test current magnitude, it yields an indication of the blood impedance in the heart chamber rather than the thoracic impedance. The measured blood impedance is used to compensate the measured thoracic impedance for changes in the blood impedance.

FIG. 3 is a block diagram illustrating generally another example in which portions of the system 100 are implemented

in an implantable CRM or other IMD 300. The example of FIG. 3 includes an impedance test stimulus circuit 302 that, together with an impedance measurement circuit 304, provides thoracic and blood impedance measurements. In response to one or more control signals from the controller 108, an electrode configuration multiplexer 306 couples these circuits to the appropriate electrodes for the particular thoracic or blood impedance measurement. In this example, the multiplexer 306 is also coupled to a heart signal sensing circuit 308, which includes sense amplifier or other circuits for detecting from particular electrodes intrinsic electrical heart signals that include electrical depolarizations corresponding to heart contractions. The multiplexer 306 is also coupled to a therapy circuit 310, such as a pulse delivery circuit for delivering pacing, cardioversion, or defibrillation energy to particular electrodes in response to one or more control signals received from the controller 108.

In the example of FIG. 3, the DSP circuit 110 processes the thoracic impedance measurements from the impedance measurement circuit 304. The DSP circuit 110 extracts a cardiac stroke signal or a respiration signal from the thoracic impedance signal, such as by using techniques described in the above-incorporated Hartley et al. U.S. Pat. No. 6,076,015. One or both of the extracted cardiac stroke or respiration signals is provided to a blood impedance measurement synchronization circuit 312. The synchronization circuit 312 includes one or more peak-detector, level-detector, or zero-cross detector circuits to synchronize the blood impedance measurement to the same sample point of a cardiac contraction cycle or a respiration cycle. This reduces the effect of variations in one or both of these cycles on the blood impedance measurement. Similarly, the measurements can be taken under the same conditions with respect to posture or circadian cycle to reduce those effects on the blood impedance measurement. Posture can be detected using an accelerometer or other posture sensor; circadian cycle can be ascertained from a time-of-day indication provided by a clock circuit within the controller 108. Alternatively, the cardiac cycle information is extracted from the heart signal sensing circuit 308, either by itself or in combination with information from the controller 108 about when pacing or other stimulus pulses that evoke a responsive heart contraction are issued. The controller 108 computes an adjusted thoracic fluid indication 116 from the measured thoracic impedance. The adjusted thoracic fluid indication 116 is compensated for blood resistivity variations using the blood resistivity correction 114 obtained using the measured blood impedance. In a further example, the implantable medical device 300 includes a telemetry circuit 314 that communicates one of the blood-resistivity-compensated thoracic impedance or the blood resistivity and thoracic impedance measurements to an external programmer 316 or the like for further processing, storage, or display.

FIG. 4 is a flow chart illustrating generally one example of a method of providing a thoracic fluid amount indication that is compensated for any changes in blood resistivity. At 400, a thoracic impedance is detected. This may be accomplished in a number of different ways. In one illustrative example, such as described in Hartley et al. U.S. Pat. No. 6,075,015, it includes injecting a four-phase carrier signal, such as between a housing electrode 218 and a ring electrode 208. In this example, the first and third phases are +320 microampere pulses that are 20 microseconds long. The second and fourth phases are -320 microampere pulses that are 20 microseconds long. The four phases are repeated at 50 millisecond intervals to provide a carrier test current signal from which a responsive voltage can be measured. However, as discussed

elsewhere in this document, because blood resistivity varies with excitation frequency, a different excitation frequency may also be used.

The Hartley et al. U.S. Pat. No. 6,075,015 describes an exciter circuit for delivering such a test current stimulus (however, the present system can alternatively use other suitable circuits, including an arbitrary waveform generator that is capable of operating at different frequencies or of mixing different frequencies to generate an arbitrary waveform). It also describes a signal processing circuit for measuring a responsive voltage between a housing electrode 216 and a tip electrode 206. In one example, the signal processing circuit includes a preamplifier, demodulator, and bandpass filter for extracting the thoracic impedance data from the carrier signal, before conversion into digital form by an A/D converter. Further processing is performed digitally, and is performed differently in the present system 100 than in the Hartley et al. U.S. Pat. No. 6,075,015.

For example, the Hartley et al. U.S. Pat. No. 6,075,015 includes a bandpass filter that receives the output of the A/D converter. The purpose of the highpass portion of the bandpass filter is to attenuate the near-DC portion of the thoracic impedance signal, which is the signal of interest to the present system 100. Therefore, the present system 100 eliminates the highpass filter. The cutoff frequency of the remaining lowpass filter is selected to pass the near-DC portion of the thoracic impedance signal and attenuate higher frequency portions of the thoracic impedance signal, including the respiration and cardiac stroke components of the thoracic impedance signal. In one example, a programmable cutoff frequency lowpass filter is used. In another example, an adaptive cutoff frequency lowpass filter is used, such that the cutoff frequency is moved to a higher frequency for higher values of heart rate and respiration frequency, and the cutoff frequency is moved to a lower frequency for lower values of heart rate and respiration frequency.

At 402 of FIG. 4, blood impedance is detected and measured. There are a number of ways in which this can be done. In one example, the blood impedance measurement is performed in the same manner as the thoracic impedance measurement, except that measurement of the responsive voltage is across two electrodes that are both typically located in the same heart chamber or same blood vessel, such as between (1) one of the distal ring electrodes 208 or the proximal ring electrode 210; and (2) the other of the distal ring electrode 208 or the proximal ring electrode 210. Because the blood impedance is to be used to correct a thoracic fluid indication, it is typically detected and measured at or near the thorax. Alternatively, however, even an external blood impedance measurement could be used, if desired. In one example, the blood impedance is sampled under appropriate other conditions (e.g., at a like point in different cardiac cycles, at a like point in different respiration cycles, etc.).

At 404, a thoracic fluid amount indication is determined. There are a number of ways in which this can be done. In one example, the thoracic fluid amount indication is given by the value of the near-DC thoracic impedance signal, which may be averaged or otherwise filtered, if desired. In another example, a baseline value of this averaged or otherwise filtered near-DC thoracic impedance signal is obtained from the patient, and the thoracic fluid amount indication is given by the difference of the near-DC thoracic fluid impedance value (with the same or different averaging or filtering) from this baseline value.

At 406, the thoracic fluid amount indication obtained from the near-DC thoracic impedance is adjusted to compensate for changes in blood resistivity. In one example, the adjusted

thoracic fluid amount indication is given by: $TFA_{adj} = TFA_{raw} \cdot (\rho_{Blood, current}) + (\rho_{Blood, baseline})$. In this equation, TFA_{adj} is the adjusted value of the thoracic fluid amount, $(\rho_{Blood, baseline})$ is the baseline value of the blood resistivity, and $(\rho_{Blood, current})$ is the current value of the blood resistivity. In the present case, since the same electrodes are used for both the baseline and current blood resistance measurements, the resistivity ratio $(\rho_{Blood, current}) + (\rho_{Blood, baseline})$ is given by the corresponding ratio of the blood resistances, i.e., $(Z_{Blood, current}) + (Z_{Blood, baseline})$.

In a further example, such as where the implantable medical device 300 optionally includes a posture sensor or detector 318, a separate baseline impedance or resistivity is provided for different postures, since posture affects thoracic impedance measurements. In one example, a separate baseline impedance or resistivity is stored for upright postures (e.g., sitting or standing) than for recumbent postures (e.g., supine, prone, left lateral decubitus, right lateral decubitus). In a further example, a separate baseline impedance or resistivity is stored for one or more of the different subtypes of upright or recumbent postures. In compensating the thoracic fluid amount indication, the posture compensation module 320 compensates a particular resistivity measurement by using a baseline resistivity that corresponds to the then-current posture indicated by the postures detector 318. One example of a suitable posture detector 318 is a commercially available two-axis accelerometer, such as Model No. ADXL202E, manufactured by Analog Devices, Inc. of Norwood, Mass., USA.

The compensated thoracic fluid amount indication can be stored in the implantable medical device 300 or transmitted to the external device 316. Moreover, in one example, the implantable medical device 300 or external device 316 is capable of storing a history of the values of the thoracic fluid amount indication to assist the physician in managing the CHF state of the patient. In one example, the external device 316 is capable of displaying a graph, histogram or other chart of such thoracic fluid amount values.

In a further example, the implantable medical device 300 or the external device 316 determines whether heart failure decompensation, pulmonary edema, or pleural effusion is present, such as by comparing an increase in the blood-resistivity-compensated thoracic fluid amount indication to a corresponding first threshold value to deem one or more of these conditions to be present.

In yet a further example, the implantable medical device 300 or the external device 316 predicts whether heart failure decompensation, pulmonary edema, or pleural effusion is likely to become present in the future, such as by comparing an increase in the blood-resistivity-compensated thoracic fluid amount indication to a corresponding second threshold value to deem one or more of these conditions to be likely in the future. The second threshold used for the condition prediction may be different from the first threshold used for the condition detection. In one example, the second threshold value reflects a smaller increase in the thoracic fluid amount indication than the first threshold value.

In yet a further example, the implantable medical device 300 adjusts a therapy to the patient using the thoracic fluid amount indication. In one example, an increase in the thoracic fluid amount indication triggers an increase in a rate at which pacing pulses are delivered to the heart. In another example, a change in the thoracic fluid amount indication results in altering another programmable parameter of cardiac pacing or cardiac resynchronization therapy, such as, for example, atrioventricular (AV) delay, particular cardiac stimulation sites, interventricular delay, or intraventricular delay. In a

further example, a change in the thoracic fluid amount indication triggers the providing of a warning or other indication to the patient to adjust a medication level (for example, a diuretic).

Another application for the present systems, devices, and methods is in anemia detection. Anemia is a pathological condition that is often present in CHF patients. Diagnosing and treating anemia will improve a patient's cardiac function. Therefore, there is a need to detect anemia in CHF patients, for example, to communicate a diagnosis regarding the anemia status to a CHF patient's health care provider.

FIG. 5 is a flow chart illustrating generally one example of an anemia detection method. At 500, a baseline blood impedance is established. In one example, this includes obtaining one or more near-DC blood impedance measurements (typically taken within the same blood vessel or heart chamber) such as described above with respect to 402 of FIG. 4. In one example, the baseline blood impedance is established by computing a central tendency (e.g., average, median, low-pass filtered, etc.) value of a series of such measured blood impedances over a desired time interval (for example, one month).

At 502, a current blood impedance is measured. This near-DC blood impedance measurement is typically performed in the same manner and location as described above for establishing the baseline. At 504, the current blood impedance is compared to the baseline blood impedance. As described above, a higher percentage of red blood cells tends to increase blood impedance. Therefore, when the current blood impedance falls far enough below the baseline blood impedance, then anemia may be indicated. Therefore, in one example, if the current blood impedance falls below the baseline blood impedance by at least an offset threshold value, then anemia is declared to be present at 506. In one example, the offset value is a fixed or programmable percentage of the baseline blood impedance (e.g., 5%, 10%, 20%, etc.). The offset value is typically set to prevent normal physiological variations in blood impedance from triggering an anemia detection. In another example, such as by choosing a different threshold value, the comparison predicts that anemia is likely to occur (e.g., if the blood impedance falls at least 10% below its baseline value, then future anemia is predicted; if the blood impedance then falls at least 20% below its baseline value, then present anemia is declared).

In one further example, if anemia is predicted or declared present, that information is telemetered or otherwise communicated to the patient's health care provider from the implantable medical device, such as by providing such information to an external device for storage or display. In one example, such communication takes place the next time that the implantable medical device is interrogated by a programmer or other external interface. In another example, such the implantable medical device itself initiates a telemetric or other communication of such information to an external device. In yet a further example, an anemia warning is provided to the patient, either directly by the implantable medical device (e.g., an audible warning), or via an external interface device.

As discussed above, measurement of variations in blood resistivity is typically affected by the frequency of the excitation signal that are used. At higher excitation frequencies, blood cells typically become more resistive. Therefore, to yield a more sensitive measurement of anemia, it may be desirable to use a higher excitation frequency than would be used for detecting thoracic impedance, and for correcting the resulting thoracic impedance measurements for changes in blood resistivity. Alternatively, such as for measuring thoracic fluid status, if a change in blood resistivity exceeds a

certain threshold value then, in one example, the system automatically switches to a lower excitation frequency that is affected less by changes in blood resistivity.

Although much of the above discussion has emphasized correcting near-DC thoracic impedance measurements to account for changes in blood resistivity, hematocrit-related blood resistivity changes may also affect higher frequency components of the thoracic impedance signal (e.g., respiration components, cardiac stroke components, etc.), somewhat analogous to the way in which patient posture can affect such higher frequency components of the thoracic impedance signal. Aspects of the present blood resistivity measurement and correction techniques may also be used for correcting such higher-frequency components of the thoracic impedance signal. However, the effects of blood resistivity changes at higher frequency may be nonlinear, making correction with a single multiplicative correction factor difficult or impossible. Therefore, a nonlinear correction function may be used, if needed. Such a nonlinear correction function may be empirically determined. In one example, the nonlinear correction function may be implemented as a lookup table. Moreover, the higher-frequency components of the thoracic impedance signal may be used to infer thoracic fluid status even much of the above discussion focused on particular examples that extract a thoracic fluid status signal from the near-DC component of the thoracic impedance signal.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in this document and in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

What is claimed is:

1. A method comprising:

detecting a thoracic impedance signal of a thorax of a subject;

detecting a blood resistivity signal by sensing between at least two intravascular or intracardiac electrodes disposed in the same chamber of the heart or the same blood vessel; and

using a signal processing circuit, extracting physiological information from the thoracic impedance signal, the extracting physiological information including using the blood resistivity signal to reduce or eliminate an effect of a change in blood resistivity on the physiological information.

2. The method of claim 1, wherein extracting physiological information includes extracting cardiac stroke information from the thoracic impedance signal.

3. The method of claim 1, wherein extracting physiological information includes extracting respiration information from the thoracic impedance signal.

11

4. The method of claim 1, wherein extracting physiological information includes extracting an abdominal fluid indication from the thoracic impedance signal.

5. The method of claim 1, comprising filtering the thoracic impedance signal to obtain a near-DC thoracic impedance signal, wherein the physiological information is generated at least in part by using the near-DC thoracic impedance signal.

6. The method of claim 5, wherein filtering the thoracic impedance signal includes accounting for posture.

7. The method of claim 1, wherein detecting the blood resistivity includes using first and second intravascular electrodes.

8. The method of claim 1, wherein detecting the blood resistivity signal includes measuring the blood resistivity at like times during at least one of a cardiac cycle and a respiratory cycle.

9. The method of claim 1, comprising:

storing a history of the physiological information; and determining whether a physiological trend is present using the history of physiological information.

10. The method of claim 9, comprising determining whether heart failure decompensation is present using a physiological trend determination.

11. The method of claim 1, comprising transmitting the physiological information from an implantable medical device to an external device.

12. The method of claim 11, comprising displaying the physiological information on the external device.

13. A system comprising:

an implantable medical device including:

a thoracic impedance measurement circuit configured to provide a thoracic impedance signal;

a blood resistivity measurement circuit configured to provide a blood resistivity signal sensed between at least two intravascular or intracardiac electrodes disposed in the same chamber of the heart or the same blood vessel; and

a controller coupled to the blood resistivity measurement circuit, the controller configured to extract

12

physiological information from the thoracic impedance signal, the controller configured to use the blood resistivity signal to reduce or eliminate an effect of a change in blood resistivity on the physiological information.

14. The system of claim 13, wherein the controller is configured to extract cardiac stroke information from the thoracic impedance signal.

15. The system of claim 13, wherein the controller is configured to extract respiration information from the thoracic impedance signal.

16. The system of claim 13, wherein the controller is configured to extract an abdominal fluid indication from the thoracic impedance signal.

17. The system of claim 13, comprising an external device in communication with the implantable medical device, the external device configured to receive the physiological information from the implantable medical device.

18. The system of claim 17, wherein the external device is configured to display the physiological information.

19. A system comprising:

means for detecting a thoracic impedance signal of a thorax of a subject;

means for detecting a blood resistivity signal sensed between at least two intravascular or intracardiac electrodes disposed in the same chamber of the heart or the same blood vessel; and

means for extracting physiological information from the thoracic impedance signal using the blood resistivity signal to reduce or eliminate an effect of a change in blood resistivity on the physiological information.

20. The system of claim 19, wherein the means for extracting physiological information includes means for extracting one of cardiac stroke information, respiration information, or an abdominal fluid indication from the thoracic impedance signal.

* * * * *

专利名称(译)	胸阻抗检测与血电阻率补偿		
公开(公告)号	US7672718	公开(公告)日	2010-03-02
申请号	US12/139948	申请日	2008-06-16
[标]申请(专利权)人(译)	心脏起搏器股份公司		
申请(专利权)人(译)	心脏起搏器 , INC.		
当前申请(专利权)人(译)	心脏起搏器 , INC.		
[标]发明人	STAHHMANN JEFFREY E HATLESTAD JOHN D MOON BOYCE		
发明人	STAHHMANN, JEFFREY E. HATLESTAD, JOHN D. MOON, BOYCE		
IPC分类号	A61B5/00		
CPC分类号	A61B5/053 A61N1/3627 A61N1/36521		
其他公开文献	US20080249433A1		
外部链接	Espacenet USPTO		

摘要(译)

该文件讨论了心律管理装置或其他植入式医疗装置，其使用胸阻抗来确定胸腔中存在多少液体，例如用于检测或预测充血性心力衰竭，肺水肿，胸腔积液，低血压。等。由胸阻抗确定的胸液量被补偿血电阻率的变化，这可能由血细胞比容水平或其他因素的变化引起。血液电阻率补偿的胸液量可以存储在装置中或传输到外部装置以进行存储或显示。血液电阻率补偿的胸液量也可用于调整心脏起搏，心脏再同步或其他心律管理或对患者的其他治疗。该文件还讨论了用于预测或指示贫血的装置和方法的应用。

