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Lovejoy

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(54) **MEDICAL DEVICE FOR ASSESSING INTRAVASCULAR BLOOD VOLUME AND TECHNIQUE FOR USING THE SAME**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,638,640	A	2/1972	Shaw
3,721,813	A	3/1973	Condon et al.
4,586,513	A	5/1986	Hamaguri
4,603,700	A	8/1986	Nichols et al.
4,621,643	A	11/1986	New, Jr. et al.
4,653,498	A	3/1987	New, Jr. et al.
4,685,464	A	8/1987	Goldberger et al.
4,694,833	A	9/1987	Hamaguri
4,697,593	A	10/1987	Evans et al.
4,700,708	A	10/1987	New, Jr. et al.
4,714,080	A	12/1987	Edgar, Jr. et al.
4,714,341	A	12/1987	Hamaguri et al.
4,759,369	A	7/1988	Taylor
4,770,179	A	9/1988	New, Jr. et al.
4,773,422	A	9/1988	Isaacson et al.
4,776,339	A	10/1988	Schreiber
4,781,195	A	11/1988	Martin
4,796,636	A	1/1989	Branstetter et al.
4,800,495	A	1/1989	Smith
4,800,885	A	1/1989	Johnson
4,802,486	A	2/1989	Goodman et al.
4,805,623	A	2/1989	Jöbsis
4,807,630	A	2/1989	Malinouskas
4,807,631	A	2/1989	Hersh et al.
4,819,646	A	4/1989	Cheung et al.
4,819,752	A	4/1989	Zelin

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0615723	9/1994

(Continued)

OTHER PUBLICATIONS

M Shamir, L A Eidelman, Y Floman, L Kaplan and R Pizov. Pulse oximetry plethysmographic waveform during changes in blood volume.(1999) Br. J. Anaesth. 82 (2): 178-181.*

(Continued)

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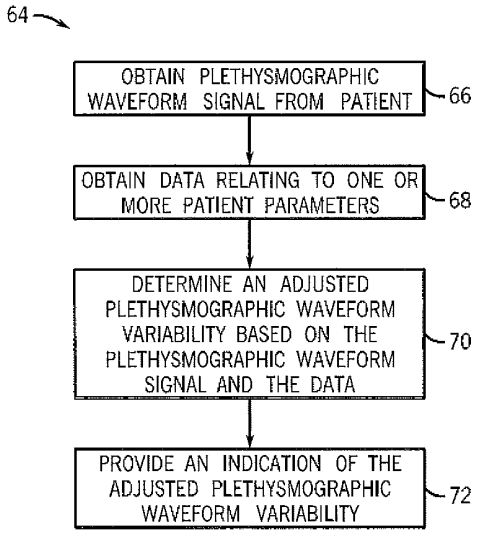
(57) **ABSTRACT**

Embodiments of the present invention relate to a system and method for determining a physiologic parameter of a patient. Specifically, embodiments of the present invention include methods and systems for correcting a pulse oximetry plethysmographic waveform variability measurement based on parameters that may influence the waveform variability. The corrected measurement may be used to estimate intravascular blood volume and/or fluid responsiveness of a patient.

18 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

4,824,242 A 4/1989 Frick et al.
4,825,872 A 5/1989 Tan et al.
4,825,879 A 5/1989 Tan et al.
4,830,014 A 5/1989 Goodman et al.
4,832,484 A 5/1989 Aoyagi et al.
4,846,183 A 7/1989 Martin
4,848,901 A 7/1989 Hood, Jr.
4,854,699 A 8/1989 Edgar, Jr.
4,859,056 A 8/1989 Prosser et al.
4,859,057 A 8/1989 Taylor et al.
4,863,265 A 9/1989 Flower et al.
4,865,038 A 9/1989 Rich et al.
4,867,557 A 9/1989 Takatani et al.
4,869,253 A 9/1989 Craig, Jr. et al.
4,869,254 A 9/1989 Stone et al.
4,880,304 A 11/1989 Jaeb et al.
4,883,055 A 11/1989 Merrick
4,883,353 A 11/1989 Hansman et al.
4,890,619 A 1/1990 Hatschek
4,892,101 A 1/1990 Cheung et al.
4,901,238 A 2/1990 Suzuki et al.
4,908,762 A 3/1990 Suzuki et al.
4,911,167 A 3/1990 Corenman et al.
4,913,150 A 4/1990 Cheung et al.
4,926,867 A 5/1990 Kanda et al.
4,927,264 A 5/1990 Shiga et al.
4,928,692 A 5/1990 Goodman et al.
4,934,372 A 6/1990 Corenman et al.
4,936,679 A 6/1990 Mersch
4,938,218 A 7/1990 Goodman et al.
4,942,877 A 7/1990 Sakai et al.
4,948,248 A 8/1990 Lehman
4,955,379 A 9/1990 Hall
4,960,126 A 10/1990 Conlon et al.
4,964,408 A 10/1990 Hink et al.
4,971,062 A 11/1990 Hasebe et al.
4,972,331 A 11/1990 Chance
4,974,591 A 12/1990 Awazu et al.
5,007,423 A 4/1991 Branstetter et al.
5,025,791 A 6/1991 Niwa
RE33,643 E 7/1991 Isaacson et al.
5,028,787 A 7/1991 Rosenthal et al.
5,040,539 A 8/1991 Schmitt et al.
5,054,488 A 10/1991 Muz
5,055,671 A 10/1991 Jones
5,058,588 A 10/1991 Kaestle
5,065,749 A 11/1991 Hasebe et al.
5,066,859 A 11/1991 Karkar et al.
5,069,213 A 12/1991 Polczynski
5,078,136 A 1/1992 Stone et al.
5,084,327 A 1/1992 Stengel
5,088,493 A 2/1992 Giannini et al.
5,090,410 A 2/1992 Saper et al.
5,094,239 A 3/1992 Jaeb et al.
5,094,240 A 3/1992 Muz
5,099,841 A 3/1992 Heinonen et al.
5,099,842 A 3/1992 Mannheimer et al.
H1039 H 4/1992 Tripp et al.
5,104,623 A 4/1992 Miller
5,109,849 A 5/1992 Goodman et al.
5,111,817 A 5/1992 Clark et al.
5,113,861 A 5/1992 Rother
5,119,815 A 6/1992 Chance
5,122,974 A 6/1992 Chance
5,125,403 A 6/1992 Culp
5,127,406 A 7/1992 Yamaguchi
5,131,391 A 7/1992 Sakai et al.
5,140,989 A 8/1992 Lewis et al.
5,152,296 A 10/1992 Simons
5,154,175 A 10/1992 Gunther
5,158,082 A 10/1992 Jones
5,167,230 A 12/1992 Chance
5,170,786 A 12/1992 Thomas et al.
5,188,108 A 2/1993 Secker et al.
5,190,038 A 3/1993 Polson et al.
5,193,542 A 3/1993 Missanelli et al.
5,193,543 A 3/1993 Yelderman
5,203,329 A 4/1993 Takatani et al.
5,209,230 A 5/1993 Swedlow et al.
5,213,099 A 5/1993 Tripp et al.
5,216,598 A 6/1993 Branstetter et al.
5,217,012 A 6/1993 Young et al.
5,217,013 A 6/1993 Lewis et al.
5,218,962 A 6/1993 Mannheimer et al.
5,224,478 A 7/1993 Sakai et al.
5,226,417 A 7/1993 Swedlow et al.
5,228,440 A 7/1993 Chung et al.
5,237,994 A 8/1993 Goldberger
5,239,185 A 8/1993 Ito et al.
5,246,002 A 9/1993 Prosser
5,246,003 A 9/1993 DeLonzor
5,247,931 A 9/1993 Norwood
5,247,932 A 9/1993 Chung et al.
5,249,576 A 10/1993 Goldberger et al.
5,253,645 A 10/1993 Friedman et al.
5,253,646 A 10/1993 Delpy et al.
5,259,381 A 11/1993 Cheung et al.
5,259,761 A 11/1993 Schnettler et al.
5,263,244 A 11/1993 Centa et al.
5,267,562 A 12/1993 Ukawa et al.
5,267,563 A 12/1993 Swedlow et al.
5,273,036 A 12/1993 Kronberg et al.
5,275,159 A 1/1994 Griebel
5,279,295 A 1/1994 Martens et al.
5,285,783 A 2/1994 Secker
5,285,784 A 2/1994 Seeker
5,287,853 A 2/1994 Vester et al.
5,291,884 A 3/1994 Heinemann et al.
5,297,548 A 3/1994 Pologe
5,299,120 A 3/1994 Kaestle
5,299,570 A 4/1994 Hatschek
5,309,908 A 5/1994 Friedman et al.
5,311,865 A 5/1994 Mayeux
5,313,940 A 5/1994 Fuse et al.
5,323,776 A 6/1994 Blakeley et al.
5,329,922 A 7/1994 Atlee, III
5,337,744 A 8/1994 Branigan
5,339,810 A 8/1994 Ivers et al.
5,343,818 A 9/1994 McCarthy et al.
5,343,869 A 9/1994 Pross et al.
5,348,003 A 9/1994 Caro
5,348,004 A 9/1994 Hollub et al.
5,349,519 A 9/1994 Kaestle
5,349,952 A 9/1994 McCarthy et al.
5,349,953 A 9/1994 McCarthy et al.
5,351,685 A 10/1994 Potratz
5,353,799 A 10/1994 Chance
5,355,880 A 10/1994 Thomas et al.
5,355,882 A 10/1994 Ukawa et al.
5,361,758 A 11/1994 Hall et al.
5,365,066 A 11/1994 Krueger, Jr. et al.
5,368,025 A 11/1994 Young et al.
5,368,026 A 11/1994 Swedlow et al.
5,368,224 A 11/1994 Richardson et al.
5,372,136 A 12/1994 Steuer et al.
5,377,675 A 1/1995 Ruskewicz et al.
5,385,143 A 1/1995 Aoyagi
5,387,122 A 2/1995 Goldberger et al.
5,390,670 A 2/1995 Centa et al.
5,392,777 A 2/1995 Swedlow et al.
5,398,680 A 3/1995 Polson et al.
5,402,777 A 4/1995 Warring et al.
5,411,023 A 5/1995 Morris, Sr. et al.
5,411,024 A 5/1995 Thomas et al.
5,413,099 A 5/1995 Schmidt et al.
5,413,100 A 5/1995 Barthelemy et al.
5,413,101 A 5/1995 Sugiura
5,413,102 A 5/1995 Schmidt et al.
5,417,207 A 5/1995 Young et al.
5,421,329 A 6/1995 Casciani et al.
5,425,360 A 6/1995 Nelson
5,425,362 A 6/1995 Siker et al.
5,427,093 A 6/1995 Ogawa et al.
5,429,128 A 7/1995 Cadell et al.
5,429,129 A 7/1995 Lovejoy et al.
5,431,159 A 7/1995 Baker et al.
5,431,170 A 7/1995 Mathews

5,437,275	A		8/1995	Amundsen et al.	5,727,547	A	3/1998	Levinson et al.
5,438,986	A		8/1995	Disch et al.	5,730,124	A	3/1998	Yamauchi
5,448,991	A		9/1995	Polson et al.	5,731,582	A	3/1998	West
5,452,717	A		9/1995	Branigan et al.	D393,830	S	4/1998	Tobler et al.
5,465,714	A		11/1995	Scheuing	5,743,260	A	4/1998	Chung et al.
5,469,845	A		11/1995	DeLonzor et al.	5,743,263	A	4/1998	Baker, Jr.
RE35,122	E		12/1995	Corenman et al.	5,746,206	A	5/1998	Mannheimer
5,482,034	A		1/1996	Lewis et al.	5,746,697	A	5/1998	Swedlow et al.
5,482,036	A		1/1996	Diab et al.	5,752,914	A	5/1998	DeLonzor et al.
5,483,646	A		1/1996	Uchikoga	5,755,226	A	5/1998	Carim et al.
5,485,847	A		1/1996	Baker, Jr.	5,758,644	A	6/1998	Diab et al.
5,490,505	A		2/1996	Diab et al.	5,760,910	A	6/1998	Lepper, Jr. et al.
5,490,523	A		2/1996	Isaacson et al.	5,766,125	A	6/1998	Aoyagi et al.
5,491,299	A		2/1996	Naylor et al.	5,766,127	A	6/1998	Pologe et al.
5,494,032	A		2/1996	Robinson et al.	5,769,785	A	6/1998	Diab et al.
5,497,771	A		3/1996	Rosenheimer	5,772,587	A	6/1998	Gratton et al.
5,499,627	A		3/1996	Steuer et al.	5,774,213	A	6/1998	Trebino et al.
5,503,148	A		4/1996	Pologe et al.	5,776,058	A	7/1998	Levinson et al.
5,505,199	A		4/1996	Kim	5,776,059	A	7/1998	Kaestle
5,507,286	A		4/1996	Solenberger	5,779,630	A	7/1998	Fein et al.
5,517,988	A		5/1996	Gerhard	5,779,631	A	7/1998	Chance
5,520,177	A		5/1996	Ogawa et al.	5,782,237	A	7/1998	Casciani et al.
5,521,851	A		5/1996	Wei et al.	5,782,756	A	7/1998	Mannheimer
5,522,388	A		6/1996	Ishikawa et al.	5,782,758	A	7/1998	Ausec et al.
5,524,617	A		6/1996	Mannheimer	5,786,592	A	7/1998	Hök
5,529,064	A		6/1996	Rall et al.	5,790,729	A	8/1998	Pologe et al.
5,533,507	A		7/1996	Potratz et al.	5,792,052	A	8/1998	Isaacson et al.
5,551,423	A		9/1996	Sugiura	5,795,292	A	8/1998	Lewis et al.
5,551,424	A		9/1996	Morrison et al.	5,797,841	A	8/1998	DeLonzor et al.
5,553,614	A		9/1996	Chance	5,800,348	A	9/1998	Kaestle
5,553,615	A		9/1996	Carim et al.	5,800,349	A	9/1998	Isaacson et al.
5,555,882	A		9/1996	Richardson et al.	5,803,910	A	9/1998	Potratz
5,558,096	A		9/1996	Palatnik	5,807,246	A	9/1998	Sakaguchi et al.
5,560,355	A		10/1996	Merchant et al.	5,807,247	A	9/1998	Merchant et al.
5,564,417	A		10/1996	Chance	5,807,248	A	9/1998	Mills
5,575,284	A		11/1996	Athan et al.	5,810,723	A	9/1998	Aldrich
5,575,285	A		11/1996	Takanashi et al.	5,810,724	A	9/1998	Gronvall
5,577,500	A		11/1996	Potratz	5,813,980	A	9/1998	Levinson et al.
5,582,169	A		12/1996	Oda et al.	5,817,008	A	10/1998	Rafert et al.
5,584,296	A		12/1996	Cui et al.	5,817,009	A	10/1998	Rosenheimer et al.
5,588,425	A		12/1996	Sackner et al.	5,817,010	A	10/1998	Hibl
5,588,427	A		12/1996	Tien	5,818,985	A	10/1998	Merchant et al.
5,590,652	A		1/1997	Inai	5,820,550	A	10/1998	Polson et al.
5,595,176	A		1/1997	Yamaura	5,823,950	A	10/1998	Diab et al.
5,596,986	A		1/1997	Goldfarb	5,823,952	A	10/1998	Levinson et al.
5,611,337	A		3/1997	Bukta	5,827,182	A	10/1998	Raley et al.
5,617,852	A		4/1997	MacGregor	5,830,135	A	11/1998	Bosque et al.
5,619,992	A		4/1997	Guthrie et al.	5,830,136	A	11/1998	DeLonzor et al.
5,626,140	A		5/1997	Feldman et al.	5,830,137	A	11/1998	Scharf
5,630,413	A		5/1997	Thomas et al.	5,830,139	A	11/1998	Abreu
5,632,272	A		5/1997	Diab et al.	5,839,439	A	11/1998	Nierlich et al.
5,632,273	A		5/1997	Suzuki	RE36,000	E	12/1998	Swedlow et al.
5,634,459	A		6/1997	Gardosi	5,842,979	A	12/1998	Jarman et al.
5,634,461	A	*	6/1997	Faithfull et al. 600/483	5,842,981	A	12/1998	Larsen et al.
5,638,593	A		6/1997	Gerhardt et al.	5,842,982	A	12/1998	Mannheimer
5,638,818	A		6/1997	Diab et al.	5,846,190	A	12/1998	Woehrle
5,645,059	A		7/1997	Fein et al.	5,851,178	A	12/1998	Aronow
5,645,060	A		7/1997	Yorkey	5,851,179	A	12/1998	Ritson et al.
5,645,440	A		7/1997	Tobler et al.	5,853,364	A	12/1998	Baker, Jr. et al.
5,660,567	A		8/1997	Nierlich et al.	5,860,919	A	1/1999	Kiani-Azarbayjany et al.
5,662,105	A		9/1997	Tien	5,865,736	A	2/1999	Baker, Jr. et al.
5,662,106	A		9/1997	Swedlow et al.	5,871,442	A	2/1999	Madarasz et al.
5,666,952	A		9/1997	Fuse et al.	5,873,821	A	2/1999	Chance et al.
5,671,529	A		9/1997	Nelson	5,879,294	A	3/1999	Anderson et al.
5,673,692	A		10/1997	Schulze et al.	5,885,213	A	3/1999	Richardson et al.
5,673,693	A		10/1997	Solenberger	5,890,929	A	4/1999	Mills et al.
5,676,139	A		10/1997	Goldberger et al.	5,891,021	A	4/1999	Dillon et al.
5,676,141	A		10/1997	Hollub	5,891,022	A	4/1999	Pologe
5,678,544	A		10/1997	DeLonzor et al.	5,891,024	A	4/1999	Jarman et al.
5,680,857	A		10/1997	Pelikan et al.	5,891,025	A	4/1999	Buschmann et al.
5,685,299	A		11/1997	Diab et al.	5,891,026	A	4/1999	Wang et al.
5,685,301	A		11/1997	Klomhaus	5,902,235	A	5/1999	Lewis et al.
5,687,719	A		11/1997	Sato et al.	5,910,108	A	6/1999	Solenberger
5,687,722	A		11/1997	Tien et al.	5,911,690	A	6/1999	Rall
5,692,503	A		12/1997	Keunstner	5,912,656	A	6/1999	Tham et al.
5,692,505	A		12/1997	Fouts	5,913,819	A	6/1999	Taylor et al.
5,709,205	A		1/1998	Bukta	5,916,154	A	6/1999	Hobbs et al.
5,713,355	A		2/1998	Richardson et al.	5,916,155	A	6/1999	Levinson et al.
5,724,967	A		3/1998	Venkatachalam	5,919,133	A	7/1999	Taylor et al.

5,919,134 A 7/1999 Diab
5,920,263 A 7/1999 Huttenhoff et al.
5,921,921 A 7/1999 Potratz et al.
5,922,607 A 7/1999 Bernreuter
5,924,979 A 7/1999 Swedlow et al.
5,924,980 A 7/1999 Coetzee
5,924,982 A 7/1999 Chin
5,924,985 A 7/1999 Jones
5,934,277 A 8/1999 Mortz
5,934,925 A 8/1999 Tobler et al.
5,940,182 A 8/1999 Lepper, Jr. et al.
5,954,644 A 9/1999 Dettling et al.
5,960,610 A 10/1999 Levinson et al.
5,961,450 A 10/1999 Merchant et al.
5,961,452 A 10/1999 Chung et al.
5,964,701 A 10/1999 Asada et al.
5,971,930 A 10/1999 Elghazzawi
5,978,691 A 11/1999 Mills
5,978,693 A 11/1999 Hamilton et al.
5,983,122 A 11/1999 Jarman et al.
5,987,343 A 11/1999 Kinast
5,991,648 A 11/1999 Levin
5,995,855 A 11/1999 Kiani et al.
5,995,856 A 11/1999 Mannheimer et al.
5,995,858 A 11/1999 Kinast
5,995,859 A 11/1999 Takahashi
5,997,343 A 12/1999 Mills et al.
5,999,834 A 12/1999 Wang et al.
6,002,952 A 12/1999 Diab et al.
6,005,658 A 12/1999 Kaluza et al.
6,006,120 A 12/1999 Levin
6,011,985 A 1/2000 Athan et al.
6,011,986 A 1/2000 Diab et al.
6,014,576 A 1/2000 Raley et al.
6,018,673 A 1/2000 Chin et al.
6,018,674 A 1/2000 Aronow
6,022,321 A 2/2000 Amano et al.
6,023,541 A 2/2000 Merchant et al.
6,026,312 A 2/2000 Shemwell et al.
6,026,314 A 2/2000 Amerov et al.
6,031,603 A 2/2000 Fine et al.
6,035,223 A 3/2000 Baker, Jr.
6,036,642 A 3/2000 Diab et al.
6,041,247 A 3/2000 Weckstrom et al.
6,044,283 A 3/2000 Fein et al.
6,047,201 A 4/2000 Jackson, III
6,061,584 A 5/2000 Lovejoy et al.
6,064,898 A 5/2000 Aldrich
6,064,899 A 5/2000 Fein et al.
6,067,462 A 5/2000 Diab et al.
6,073,038 A 6/2000 Wang et al.
6,078,833 A 6/2000 Hueber
6,081,735 A 6/2000 Diab et al.
6,081,742 A 6/2000 Amano et al.
6,083,157 A 7/2000 Noller
6,083,172 A 7/2000 Baker, Jr. et al.
6,088,607 A * 7/2000 Diab et al. 600/322
6,094,592 A 7/2000 Yorkey et al.
6,095,974 A 8/2000 Shemwell et al.
6,099,481 A 8/2000 Daniels et al.
6,104,938 A 8/2000 Huiku et al.
6,112,107 A 8/2000 Hannula
6,113,541 A 9/2000 Dias et al.
6,115,621 A 9/2000 Chin
6,120,460 A 9/2000 Abreu
6,122,535 A 9/2000 Kaestle et al.
6,133,994 A 10/2000 Mathews et al.
6,134,460 A 10/2000 Chance
6,135,952 A 10/2000 Coetzee
6,144,444 A 11/2000 Haworth et al.
6,144,867 A 11/2000 Walker et al.
6,144,868 A 11/2000 Parker
6,149,481 A 11/2000 Wang et al.
6,150,951 A 11/2000 Olejniczak
6,151,107 A 11/2000 Schöllermann et al.
6,151,518 A 11/2000 Hayashi
6,152,754 A 11/2000 Gerhardt et al.
6,154,667 A 11/2000 Miura et al.
6,157,850 A 12/2000 Diab et al.
6,163,715 A 12/2000 Larsen et al.
6,165,005 A 12/2000 Mills et al.
6,173,196 B1 1/2001 Delonzor et al.
6,178,343 B1 1/2001 Bindszus et al.
6,181,958 B1 1/2001 Steuer et al.
6,181,959 B1 1/2001 Schöllermann et al.
6,184,521 B1 2/2001 Coffin, IV et al.
6,188,470 B1 2/2001 Grace
6,192,260 B1 2/2001 Chance
6,195,575 B1 2/2001 Levinson
6,198,951 B1 3/2001 Kosuda et al.
6,206,830 B1 3/2001 Diab et al.
6,213,952 B1 4/2001 Finarov et al.
6,217,523 B1 4/2001 Amano et al.
6,222,189 B1 4/2001 Misner et al.
6,226,539 B1 5/2001 Potratz
6,226,540 B1 5/2001 Bernreuter et al.
6,229,856 B1 5/2001 Diab et al.
6,230,035 B1 5/2001 Aoyagi et al.
6,233,470 B1 5/2001 Tsuchiya
6,236,871 B1 5/2001 Tsuchiya
6,236,872 B1 5/2001 Diab et al.
6,240,305 B1 5/2001 Tsuchiya
6,253,097 B1 6/2001 Aronow et al.
6,253,098 B1 6/2001 Walker et al.
6,256,523 B1 7/2001 Diab et al.
6,256,524 B1 7/2001 Walker et al.
6,261,236 B1 7/2001 Grimblatov
6,263,221 B1 7/2001 Chance et al.
6,263,222 B1 7/2001 Diab et al.
6,263,223 B1 7/2001 Sheperd et al.
6,266,546 B1 7/2001 Steuer et al.
6,266,547 B1 7/2001 Walker et al.
6,272,363 B1 8/2001 Casciani et al.
6,278,522 B1 8/2001 Lepper, Jr. et al.
6,280,213 B1 8/2001 Tobler et al.
6,280,381 B1 8/2001 Malin et al.
6,285,894 B1 9/2001 Oppelt et al.
6,285,895 B1 9/2001 Ristolainen et al.
6,285,896 B1 9/2001 Tobler et al.
6,298,252 B1 10/2001 Kovach et al.
6,308,089 B1 10/2001 Von der Ruhr et al.
6,312,393 B1 11/2001 Abreu
6,321,100 B1 11/2001 Parker
6,330,468 B1 12/2001 Scharf
6,334,065 B1 12/2001 Al-Ali et al.
6,339,715 B1 1/2002 Bahr et al.
6,343,223 B1 1/2002 Chin et al.
6,343,224 B1 1/2002 Parker
6,349,228 B1 2/2002 Kiani et al.
6,351,658 B1 2/2002 Middleman et al.
6,353,750 B1 3/2002 Kimura et al.
6,356,774 B1 3/2002 Bernstein et al.
6,360,113 B1 3/2002 Dettling
6,360,114 B1 3/2002 Diab et al.
6,361,501 B1 3/2002 Amano et al.
6,363,269 B1 3/2002 Hanna et al.
6,370,408 B1 4/2002 Merchant et al.
6,370,409 B1 4/2002 Chung et al.
6,374,129 B1 4/2002 Chin et al.
6,377,829 B1 4/2002 Al-Ali et al.
6,381,479 B1 4/2002 Norris
6,381,480 B1 4/2002 Stoddart et al.
6,385,471 B1 5/2002 Mortz
6,385,821 B1 5/2002 Modgil et al.
6,388,240 B2 5/2002 Schulz et al.
6,393,310 B1 5/2002 Kuenster
6,397,091 B2 5/2002 Diab et al.
6,397,092 B1 5/2002 Norris et al.
6,397,093 B1 5/2002 Aldrich
6,400,971 B1 6/2002 Finarov et al.
6,400,972 B1 6/2002 Fine
6,402,690 B1 6/2002 Rhee et al.
6,408,198 B1 6/2002 Hanna et al.
6,411,832 B1 6/2002 Guthermann
6,411,833 B1 6/2002 Baker, Jr. et al.
6,415,236 B2 7/2002 Kobayashi et al.
6,419,671 B1 7/2002 Lemberg
6,421,549 B1 7/2002 Jacques

6,430,423 B2 8/2002 DeLonzor et al.
6,430,513 B1 8/2002 Wang et al.
6,430,525 B1 8/2002 Weber et al.
6,434,408 B1 8/2002 Heckel et al.
6,438,399 B1 8/2002 Kurth
6,449,501 B1 9/2002 Reuss
6,453,183 B1 9/2002 Walker
6,453,184 B1 9/2002 Hyogo et al.
6,456,862 B2 9/2002 Benni
6,461,305 B1 10/2002 Schnall
6,463,310 B1 10/2002 Swedlow et al.
6,463,311 B1 10/2002 Diab
6,466,808 B1 10/2002 Chin et al.
6,466,809 B1 10/2002 Riley
6,470,199 B1 10/2002 Kopotic et al.
6,470,200 B2 10/2002 Walker et al.
6,480,729 B2 11/2002 Stone
6,487,439 B1 11/2002 Skladnev et al.
6,490,466 B1 12/2002 Fein et al.
6,496,711 B1 12/2002 Athan et al.
6,498,942 B1 12/2002 Esenaliev et al.
6,501,974 B2 12/2002 Huiku
6,501,975 B2 12/2002 Diab et al.
6,505,060 B1 1/2003 Norris
6,505,061 B2 1/2003 Larson
6,505,133 B1 1/2003 Hanna et al.
6,510,329 B2 1/2003 Heckel
6,510,331 B1 1/2003 Williams et al.
6,512,937 B2 1/2003 Blank et al.
6,515,273 B2 2/2003 Al-Ali
6,519,484 B1 2/2003 Lovejoy et al.
6,519,486 B1 2/2003 Edgar, Jr. et al.
6,519,487 B1 2/2003 Parker
6,525,386 B1 2/2003 Mills et al.
6,526,300 B1 2/2003 Kiani et al.
6,526,301 B2 2/2003 Larsen et al.
6,541,756 B2 4/2003 Schulz et al.
6,542,764 B1 4/2003 Al-Ali et al.
6,544,193 B2 4/2003 Abreu
6,546,267 B1 4/2003 Sugiura et al.
6,549,795 B1 4/2003 Chance
6,553,241 B2 4/2003 Mannheimer et al.
6,553,242 B1 4/2003 Sarussi
6,553,243 B2 4/2003 Gurley
6,556,852 B1 4/2003 Schulze et al.
6,560,470 B1 5/2003 Pologe
6,564,077 B2 5/2003 Mortara
6,564,088 B1 5/2003 Soller et al.
6,571,113 B1 5/2003 Fein et al.
6,571,114 B1 5/2003 Koike et al.
6,574,491 B2 6/2003 Elghazzawi
6,580,086 B1 6/2003 Schulz et al.
6,584,336 B1 6/2003 Ali et al.
6,587,703 B2 7/2003 Cheng et al.
6,587,704 B1 7/2003 Fine et al.
6,589,172 B2 7/2003 Williams et al.
6,591,122 B2 7/2003 Schmitt
6,591,123 B2 7/2003 Fein et al.
6,594,511 B2 7/2003 Stone et al.
6,594,512 B2 7/2003 Huang
6,594,513 B1 7/2003 Jobsis et al.
6,597,931 B1 7/2003 Cheng et al.
6,597,933 B2 7/2003 Kiani et al.
6,600,940 B1 7/2003 Fein et al.
6,606,509 B2 8/2003 Schmitt
6,606,510 B2 8/2003 Swedlow et al.
6,606,511 B1 8/2003 Ali et al.
6,606,512 B2 8/2003 Muz et al.
6,615,064 B1 9/2003 Aldrich
6,615,065 B1 9/2003 Barrett et al.
6,618,602 B2 9/2003 Levin et al.
6,622,034 B1 9/2003 Gorski et al.
6,622,095 B2 9/2003 Kobayashi et al.
6,628,975 B1 9/2003 Fein et al.
6,631,281 B1 10/2003 Kästle
6,643,530 B2 11/2003 Diab et al.
6,643,531 B1 11/2003 Katarow
6,647,279 B2 11/2003 Pologe
6,647,280 B2 11/2003 Bahr et al.
6,650,917 B2 * 11/2003 Diab et al. 600/323
6,650,918 B2 11/2003 Terry
6,654,621 B2 11/2003 Palatnik et al.
6,654,622 B1 11/2003 Eberhard et al.
6,654,623 B1 11/2003 Kästle
6,654,624 B2 11/2003 Diab et al.
6,658,276 B2 12/2003 Kianl et al.
6,658,277 B2 12/2003 Wasserman
6,662,030 B2 12/2003 Khalil et al.
6,662,033 B2 12/2003 Casciani et al.
6,665,551 B1 12/2003 Suzuki
6,668,182 B2 12/2003 Hubelbank
6,668,183 B2 12/2003 Hicks et al.
6,671,526 B1 12/2003 Aoyagi et al.
6,671,528 B2 12/2003 Steuer et al.
6,671,530 B2 12/2003 Chung et al.
6,671,531 B2 12/2003 Al-Ali et al.
6,671,532 B1 12/2003 Fudge et al.
6,675,031 B1 1/2004 Porges et al.
6,678,543 B2 1/2004 Diab et al.
6,681,126 B2 1/2004 Solenberger
6,681,128 B2 1/2004 Steuer et al.
6,681,454 B2 1/2004 Modgil et al.
6,684,090 B2 1/2004 Ali et al.
6,684,091 B2 1/2004 Parker
6,690,958 B1 2/2004 Walker et al.
6,694,160 B2 2/2004 Chin
6,697,653 B2 2/2004 Hanna
6,697,655 B2 2/2004 Sueppel et al.
6,697,656 B1 2/2004 Al-Ali
6,697,658 B2 2/2004 Al-Ali
RE38,476 E 3/2004 Diab et al.
6,699,194 B1 3/2004 Diab et al.
6,699,199 B2 3/2004 Asada et al.
6,701,170 B2 3/2004 Stetson
6,702,752 B2 3/2004 Dekker
6,707,257 B2 3/2004 Norris
6,708,048 B1 3/2004 Chance
6,708,049 B1 3/2004 Berson et al.
6,709,402 B2 3/2004 Dekker
6,711,424 B1 3/2004 Fine et al.
6,711,425 B1 3/2004 Reuss
6,714,803 B1 3/2004 Mortz
6,714,804 B2 3/2004 Al-Ali et al.
6,714,805 B2 3/2004 Jeon et al.
RE38,492 E 4/2004 Diab et al.
6,719,686 B2 4/2004 Coakley et al.
6,719,705 B2 4/2004 Mills
6,720,734 B2 4/2004 Norris
6,721,584 B2 4/2004 Baker, Jr. et al.
6,721,585 B1 4/2004 Parker
6,725,074 B1 4/2004 Kästle
6,725,075 B2 4/2004 Al-Ali
6,731,963 B2 5/2004 Finarov et al.
6,731,967 B1 5/2004 Turcott
6,735,459 B2 5/2004 Parker
6,745,060 B2 6/2004 Diab et al.
6,745,061 B1 6/2004 Hicks et al.
6,748,253 B2 6/2004 Norris et al.
6,748,254 B2 6/2004 O'Neil et al.
6,754,515 B1 6/2004 Pologe
6,754,516 B2 6/2004 Mannheimer
6,760,607 B2 7/2004 Al-All
6,760,609 B2 7/2004 Jacques
6,760,610 B2 7/2004 Tschupp et al.
6,763,255 B2 7/2004 DeLonzor et al.
6,763,256 B2 7/2004 Kimball et al.
6,770,028 B1 * 8/2004 Ali et al. 600/300
6,771,994 B2 8/2004 Kiani et al.
6,773,397 B2 8/2004 Kelly
6,778,923 B2 8/2004 Norris et al.
6,780,158 B2 8/2004 Yarita
6,785,568 B2 8/2004 Chance
6,792,300 B1 9/2004 Diab et al.
6,793,654 B2 9/2004 Lemberg
6,801,797 B2 10/2004 Mannheimer et al.
6,801,798 B2 10/2004 Geddes et al.
6,801,799 B2 10/2004 Mendelson
6,801,802 B2 10/2004 Sitzman et al.

6,802,812 B1 10/2004 Walker et al.
6,805,673 B2 10/2004 Dekker
6,810,277 B2 10/2004 Edgar, Jr. et al.
6,813,511 B2 11/2004 Diab et al.
6,816,741 B2 11/2004 Diab
6,819,950 B2 11/2004 Mills
6,822,564 B2 11/2004 Al-Ali
6,825,619 B2 11/2004 Norris
6,826,419 B2 11/2004 Diab et al.
6,829,496 B2 12/2004 Nagai et al.
6,830,711 B2 12/2004 Mills et al.
6,836,679 B2 12/2004 Baker, Jr. et al.
6,839,579 B1 1/2005 Chin
6,839,580 B2 1/2005 Zonios et al.
6,839,582 B2 1/2005 Heckel
6,839,659 B2 1/2005 Tarassenko et al.
6,842,635 B1 1/2005 Parker
6,845,256 B2 1/2005 Chin et al.
6,850,787 B2 2/2005 Weber et al.
6,850,788 B2 2/2005 Al-Ali
6,850,789 B2 2/2005 Schweitzer, Jr. et al.
6,861,639 B2 3/2005 Al-Ali
6,863,652 B2 3/2005 Huang et al.
6,865,407 B2 3/2005 Kimball et al.
6,873,865 B2 3/2005 Steuer et al.
6,879,850 B2 4/2005 Kimball
6,882,874 B2 4/2005 Huiku
6,889,153 B2 5/2005 Dietiker
6,898,452 B2 5/2005 Al-Ali et al.
6,909,912 B2 6/2005 Melker et al.
6,912,413 B2 6/2005 Rantala et al.
6,916,289 B2 7/2005 Schnall
6,920,345 B2 7/2005 Al-Ali et al.
6,931,269 B2 8/2005 Terry
6,934,570 B2 8/2005 Kiani et al.
6,939,307 B1 9/2005 Dunlop
6,941,162 B2 9/2005 Fudge et al.
6,947,781 B2 9/2005 Asada et al.
6,949,081 B1 9/2005 Chance
6,950,687 B2 9/2005 Al-Ali
6,961,598 B2 11/2005 Diab
6,963,767 B2 11/2005 Rantala et al.
6,971,580 B2 12/2005 Zhu et al.
6,982,928 B2 1/2006 Al-Ali
6,983,178 B2 1/2006 Fine et al.
6,985,763 B2 1/2006 Boas et al.
6,985,764 B2 1/2006 Mason et al.
6,990,426 B2 1/2006 Yoon et al.
6,992,772 B2 1/2006 Block et al.
6,993,371 B2 1/2006 Kiani et al.
6,993,372 B2 1/2006 Fine et al.
6,996,427 B2 2/2006 Ali et al.
7,003,338 B2 2/2006 Weber et al.
7,003,339 B2 2/2006 Diab et al.
7,006,855 B1 2/2006 Sarussi
7,006,856 B2 2/2006 Baker, Jr. et al.
7,016,715 B2 3/2006 Stetson
7,020,507 B2 3/2006 Scharf et al.
7,024,233 B2 4/2006 Ali et al.
7,024,235 B2 4/2006 Melker et al.
7,025,728 B2 4/2006 Ito et al.
7,027,849 B2 4/2006 Al-Ali et al.
7,027,850 B2 4/2006 Wasserman
7,035,697 B1 4/2006 Brown
7,039,449 B2 5/2006 Al-Ali
7,043,289 B2 5/2006 Fine et al.
7,047,055 B2 5/2006 Boaz et al.
7,047,056 B2 5/2006 Hannula et al.
7,060,035 B2 6/2006 Wasserman et al.
7,062,307 B2 6/2006 Norris et al.
7,067,893 B2 6/2006 Mills et al.
7,072,701 B2 7/2006 Chen et al.
7,072,702 B2 7/2006 Edgar, Jr. et al.
7,079,880 B2 7/2006 Stetson
7,085,597 B2 8/2006 Fein et al.
7,096,054 B2 8/2006 Abdul-Hafiz et al.
7,107,088 B2 9/2006 Aceti
7,113,815 B2 9/2006 O'Neil et al.
7,123,950 B2 10/2006 Mannheimer
7,127,278 B2 10/2006 Melker et al.
7,130,671 B2 10/2006 Baker, Jr. et al.
7,132,641 B2 11/2006 Schulz et al.
7,133,711 B2 11/2006 Chernoguz et al.
7,139,599 B2 11/2006 Terry
7,142,901 B2 11/2006 Kiani et al.
7,162,288 B2 1/2007 Nordstrom
7,190,987 B2 3/2007 Lindekugel et al.
7,198,778 B2 4/2007 Achilefu et al.
7,209,775 B2 4/2007 Bae et al.
7,215,984 B2 5/2007 Diab et al.
7,225,006 B2 5/2007 Al-Ali et al.
7,236,811 B2 6/2007 Schmitt
7,248,910 B2 7/2007 Li et al.
7,254,433 B2 8/2007 Diab et al.
7,254,434 B2 8/2007 Schulz et al.
7,263,395 B2 8/2007 Chan et al.
7,272,426 B2 9/2007 Scmid
7,280,858 B2 10/2007 Al-Ali et al.
7,295,866 B2 11/2007 Al-Ali et al.
7,305,262 B2 12/2007 Brodnick et al.
7,315,753 B2 1/2008 Baker, Jr. et al.
2001/0005773 A1 6/2001 Larsen et al.
2001/0020122 A1 9/2001 Steuer et al.
2001/0021803 A1 9/2001 Blank et al.
2001/0039376 A1 11/2001 Steuer et al.
2001/0044700 A1 11/2001 Kobayashi et al.
2001/0051767 A1 12/2001 Williams et al.
2002/0026106 A1 2/2002 Khalil et al.
2002/0026109 A1 2/2002 Diab et al.
2002/0028990 A1 3/2002 Sheperd et al.
2002/0035318 A1 3/2002 Mannheimer et al.
2002/0038078 A1 3/2002 Ito
2002/0038079 A1 3/2002 Steuer et al.
2002/0042558 A1 4/2002 Mendelson
2002/0049389 A1 4/2002 Abreu
2002/0062071 A1 5/2002 Diab et al.
2002/0068859 A1 6/2002 Knopp
2002/0111748 A1 8/2002 Kobayashi et al.
2002/0123672 A1* 9/2002 Christophersom et al. ... 600/300
2002/0128544 A1 9/2002 Diab et al.
2002/0133067 A1 9/2002 Jackson, III
2002/0133068 A1 9/2002 Huiku
2002/0156354 A1 10/2002 Larson
2002/0161287 A1 10/2002 Schmitt
2002/0161290 A1 10/2002 Chance
2002/0165439 A1* 11/2002 Schmitt 600/309
2002/0173706 A1 11/2002 Takatani
2002/0173709 A1 11/2002 Fine et al.
2002/0190863 A1 12/2002 Lynn
2002/0198442 A1 12/2002 Rantala et al.
2002/0198443 A1 12/2002 Ting
2003/0018243 A1 1/2003 Gerhardt et al.
2003/0023140 A1 1/2003 Chance
2003/0036690 A1 2/2003 Geddes et al.
2003/0045785 A1 3/2003 Diab et al.
2003/0055324 A1 3/2003 Wasserman
2003/0060693 A1 3/2003 Monfre et al.
2003/0073889 A1 4/2003 Keilbach et al.
2003/0073890 A1 4/2003 Hanna
2003/0100840 A1 5/2003 Sugiura et al.
2003/0132495 A1 7/2003 Mills et al.
2003/0135099 A1 7/2003 Al-Ali
2003/0139687 A1 7/2003 Abreu
2003/0144584 A1 7/2003 Mendelson
2003/0162414 A1 8/2003 Schulz et al.
2003/0171662 A1 9/2003 O'Connor et al.
2003/0176776 A1 9/2003 Huiku
2003/0181799 A1 9/2003 Lindekugel et al.
2003/0187337 A1 10/2003 Tarassenko et al.
2003/0195402 A1 10/2003 Fein et al.
2003/0197679 A1 10/2003 Ali et al.
2003/0212316 A1 11/2003 Leiden et al.
2003/0220548 A1 11/2003 Schmitt
2003/0220576 A1 11/2003 Diab
2003/0225323 A1 12/2003 Kiani et al.
2003/0225337 A1 12/2003 Scharf et al.
2003/0236452 A1 12/2003 Melker et al.
2003/0236647 A1 12/2003 Yoon et al.

2004/0006261	A1	1/2004	Swedlow et al.
2004/0010188	A1	1/2004	Wasserman et al.
2004/0024297	A1	2/2004	Chen et al.
2004/0024326	A1	2/2004	Yeo et al.
2004/0034293	A1	2/2004	Kimball
2004/0039272	A1	2/2004	Abdul-Hafiz et al.
2004/0039273	A1	2/2004	Terry
2004/0054269	A1	3/2004	Rantala et al.
2004/0054270	A1	3/2004	Pewzner et al.
2004/0054291	A1	3/2004	Schulz et al.
2004/0059209	A1	3/2004	Al-Ali et al.
2004/0059210	A1	3/2004	Stetson
2004/0064020	A1	4/2004	Diab et al.
2004/0068164	A1	4/2004	Diab et al.
2004/0087846	A1	5/2004	Wasserman
2004/0092805	A1	5/2004	Yarita
2004/0097797	A1	5/2004	Porges et al.
2004/0098009	A1	5/2004	Boecker et al.
2004/0107065	A1	6/2004	Al-Ali et al.
2004/0116788	A1	6/2004	Chernoguz et al.
2004/0116789	A1	6/2004	Boaz et al.
2004/0117891	A1	6/2004	Hannula et al.
2004/0122300	A1	6/2004	Boas et al.
2004/0122302	A1	6/2004	Mason et al.
2004/0127779	A1	7/2004	Steuer et al.
2004/0133087	A1	7/2004	Ali et al.
2004/0133088	A1	7/2004	Al-Ali et al.
2004/0138538	A1	7/2004	Stetson
2004/0138540	A1	7/2004	Baker, Jr. et al.
2004/0143172	A1	7/2004	Fudge et al.
2004/0147821	A1	7/2004	Al-Ali et al.
2004/0147822	A1	7/2004	Al-Ali et al.
2004/0147823	A1	7/2004	Kiani et al.
2004/0147824	A1	7/2004	Diab et al.
2004/0152965	A1	8/2004	Diab et al.
2004/0158134	A1	8/2004	Diab et al.
2004/0158135	A1	8/2004	Baker, Jr. et al.
2004/0162472	A1	8/2004	Berson et al.
2004/0171920	A1	9/2004	Mannheimer et al.
2004/0171948	A1	9/2004	Terry
2004/0176670	A1	9/2004	Takamura et al.
2004/0176671	A1	9/2004	Fine et al.
2004/0181133	A1	9/2004	Al-Ali et al.
2004/0181134	A1	9/2004	Baker, Jr. et al.
2004/0186358	A1	9/2004	Chernow et al.
2004/0199063	A1	10/2004	O'Neil et al.
2004/0204636	A1	10/2004	Diab et al.
2004/0204637	A1	10/2004	Diab et al.
2004/0204638	A1	10/2004	Diab et al.
2004/0204639	A1	10/2004	Casciani et al.
2004/0204865	A1	10/2004	Lee et al.
2004/0210146	A1	10/2004	Diab et al.
2004/0215069	A1	10/2004	Mannheimer
2004/0230106	A1	11/2004	Schmitt et al.
2004/0230107	A1	11/2004	Asada et al.
2004/0230108	A1	11/2004	Melker et al.
2004/0236196	A1	11/2004	Diab et al.
2004/0242980	A1	12/2004	Kiani et al.
2004/0249252	A1	12/2004	Fine et al.
2004/0257557	A1	12/2004	Block et al.
2004/0260161	A1	12/2004	Melker et al.
2004/0260186	A1	12/2004	Dekker
2004/0267103	A1	12/2004	Li et al.
2004/0267104	A1	12/2004	Hannula et al.
2004/0267140	A1	12/2004	Ito et al.
2005/0004479	A1	1/2005	Townsend et al.
2005/0010092	A1	1/2005	Weber et al.
2005/0020887	A1	1/2005	Goldberg
2005/0020894	A1	1/2005	Norris et al.
2005/0033128	A1	2/2005	Ali et al.
2005/0033129	A1	2/2005	Edgar, Jr. et al.
2005/0043599	A1	2/2005	O'Mara
2005/0043600	A1	2/2005	Diab et al.
2005/0049470	A1	3/2005	Terry
2005/0049471	A1	3/2005	Aceti
2005/0075550	A1	4/2005	Lindekugel
2005/0080323	A1	4/2005	Kato
2005/0101850	A1	5/2005	Parker
2005/0113656	A1	5/2005	Chance
2005/0168722	A1	8/2005	Forstner et al.
2005/0177034	A1	8/2005	Beaumont
2005/0192488	A1	9/2005	Bryenton et al.
2005/0197548	A1	9/2005	Dietiker
2005/0203357	A1	9/2005	Debreczeny et al.
2005/0228248	A1	10/2005	Dietiker
2005/0267346	A1	12/2005	Faber et al.
2005/0277819	A1	12/2005	Kiani et al.
2005/0283059	A1	12/2005	Iyer et al.
2005/0284476	A1*	12/2005	Blanch et al. 128/204.21
2006/0009688	A1	1/2006	Lamego et al.
2006/0015021	A1	1/2006	Cheng
2006/0020181	A1	1/2006	Schmitt
2006/0025660	A1	2/2006	Swedlow et al.
2006/0030763	A1	2/2006	Mannheimer et al.
2006/0052680	A1	3/2006	Diab
2006/0058594	A1	3/2006	Ishizuka et al.
2006/0058683	A1	3/2006	Chance
2006/0058691	A1	3/2006	Kiani
2006/0064024	A1	3/2006	Schnall
2006/0084852	A1	4/2006	Mason et al.
2006/0089547	A1	4/2006	Sarussi
2006/0106294	A1	5/2006	Maser et al.
2006/0195028	A1	8/2006	Hannula et al.
2006/0224058	A1	10/2006	Mannheimer
2006/0247501	A1	11/2006	Ali
2006/0258921	A1	11/2006	Addison et al.
2007/0032710	A1	2/2007	Raridan et al.
2007/0032712	A1	2/2007	Raridan et al.
2007/0032715	A1	2/2007	Eghbal et al.
2007/0073126	A1	3/2007	Raridan, Jr.
2007/0179386	A1	8/2007	Michard et al.
2008/0200775	A1	8/2008	Lynn
2009/0076462	A1	3/2009	Kiani

FOREIGN PATENT DOCUMENTS

EP	0630203		12/1994
JP	63275325		11/1988
JP	2005034472		2/2005
WO	WO9639927		12/1996
WO	WO0021438		4/2000
WO	WO0140776		6/2001
WO	WO0176461		10/2001
WO	WO0176471		10/2001
WO	02/075289	A2	9/2002
WO	WO03039326		5/2003
WO	2006086085	A2	8/2006
WO	2008073855	A2	6/2008

OTHER PUBLICATIONS

Variations in arterial blood pressure and photoplethysmography during mechanical ventilation. Natalini G, Rosano A, Franceschetti ME, Facchetti P, Bernardini A. Anesth Analg. Nov. 2006;103(5):1182-8.*

Barnum, P.T., et al.; "Novel Pulse Oximetry Technology Capable of Reliable Bradycardia Monitoring in the Neonate," Respiratory Care, vol. 42, No. 1, p. 1072 (Nov. 1997).

Pickett, John, et al.; "Pulse Oximetry and PPG Measurements in Plastic Surgery," *Proceedings—19th International Conference—IEEE/EMBS*, Chicago, Illinois, Oct. 30-Nov. 2, 1997, pp. 2330-2332.

East, Christine E., et al.; "Fetal Oxygen Saturation and Uterine Contractions During Labor," *American Journal of Perinatology*, vol. 15, No. 6, pp. 345-349 (Jun. 1998).

Seelbach-Göbel, Birgit, et al.; "The prediction of fetal acidosis by means of intrapartum fetal pulse oximetry," *Am J. Obstet. Gynecol.*, vol. 180, No. 1, Part 1, pp. 73-81 (1999).

Nilsson, Lena, et al.; "Monitoring of Respiratory Rate in Postoperative Care Using a New Photoplethysmographic Technique," *Journal of Clinical Monitoring and Computing*, vol. 16, pp. 309-315 (2000).

Maletras, Francois-Xavier, et al.; "Construction and calibration of a new design of Fiber Optic Respiratory Plethysmograph (FORP)," *Optomechanical Design and Engineering, Proceedings of SPIE*, vol. 4444, pp. 285-293 (2001).

Earthrowl-Gould, T., et al.; "Chest and abdominal surface motion measurement for continuous monitoring of respiratory function," *Proc. Instn Mech Engrs*, V215, Part H; pp. 515-520 (2001).

Yoon, Gilwon, et al.; Multiple diagnosis based on Photoplethysmography: hematocrit, SpO2, pulse and respiration, *Optics in Health Care and Biomedical optics: Diagnostics and Treatment; Proceedings of the SPIE*, vol. 4916; pp. 185-188 (2002).

A. Johansson; "Neural network for photoplethysmographic respiratory rate monitoring," *Medical & Biological Engineering & Computing*, vol. 41, pp. 242-248 (2003).

Johnston, W.S., et al.; "Extracting Breathing Rate Infromation from a Wearable Reflectance Pulse Oximeter Sensor," *Proceedings of the 26th Annual International conference of the IEEE EMBS*, San Francisco, California; Sep. 1-5, 2004; pp. 5388-5391.

Spigulis, Janis, et al.; "Optical multi-channel sensing of skin blood pulsations," *Optical Sensing, Proceedings of SPIE*, vol. 5459, pp. 46-53 (2004).

PCT Notification of Transmittal of the International Search Report and the Written Opinion of the the International Searching Authority, or the Declaration, Date of mailing: Jun. 17, 2010, Applicants file reference: H-RM-01331 WO, International application No. PCT/US2010/027508, International filing date: Mar. 16, 2010, Applicant: Nellcor Puritan Bennett LLC.

* cited by examiner

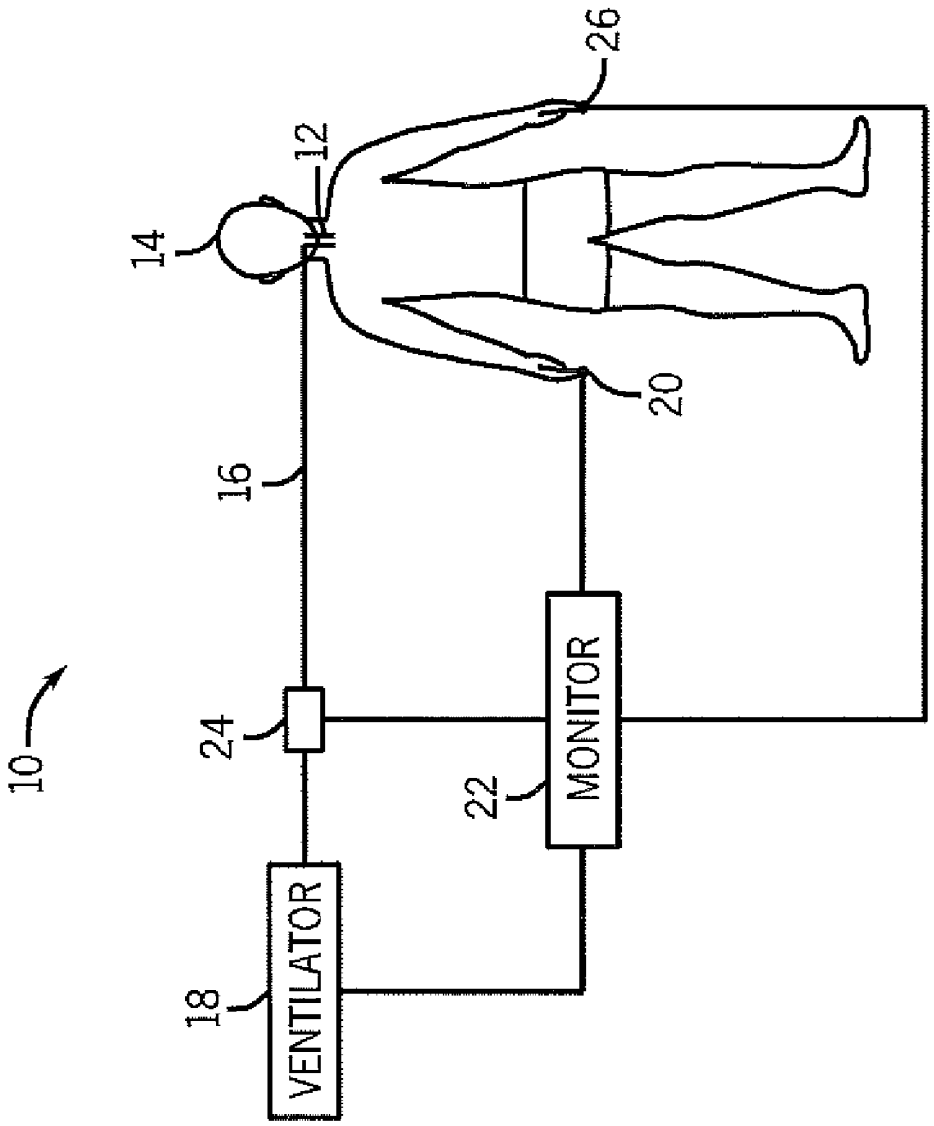


FIG. 1

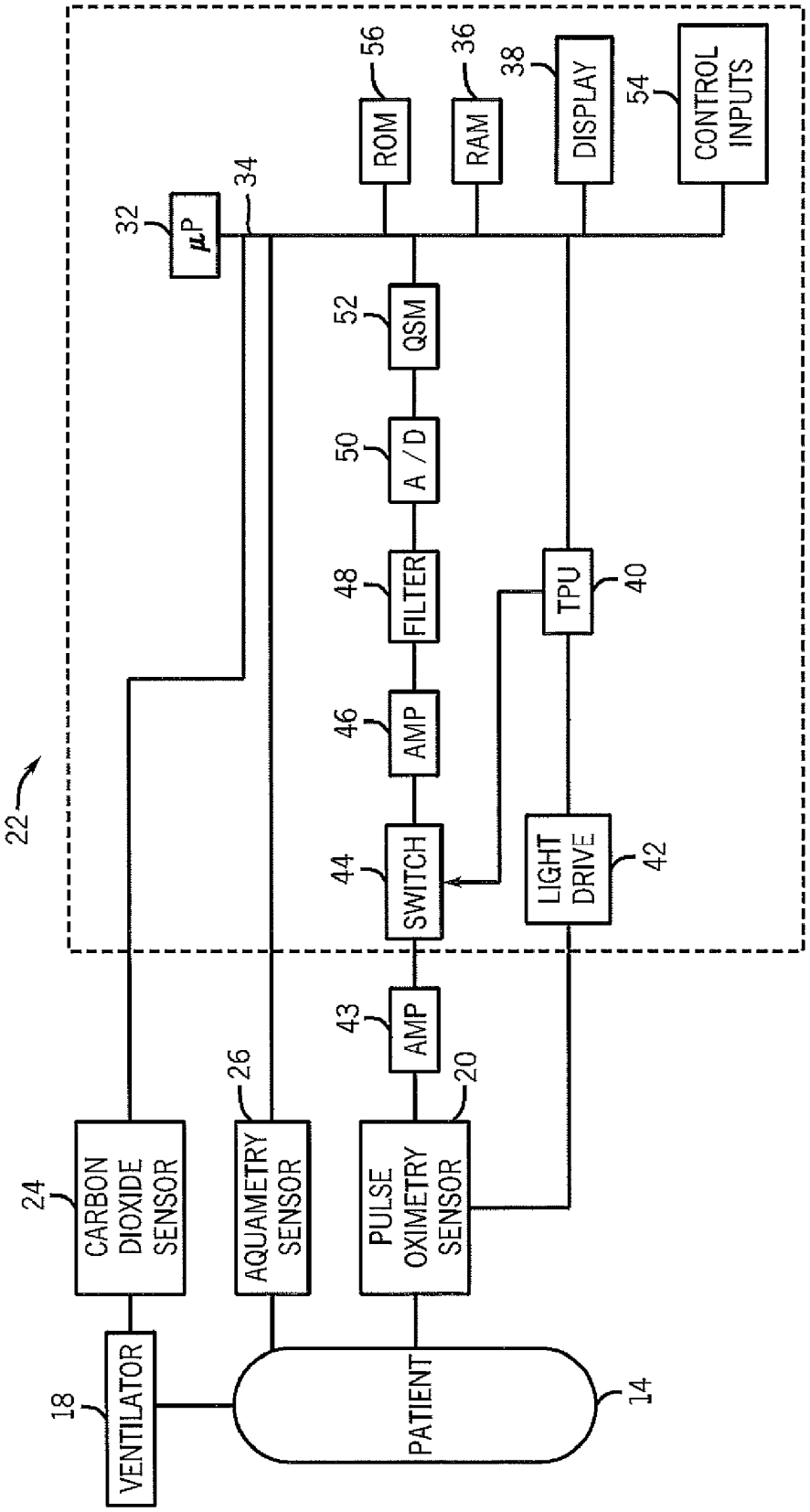

22
32
μP
34
ROM
56
RAM
36
DISPLAY
38
CONTROL INPUTS
54
QSM
52
A / D
50
FILTER
48
AMP
46
SWITCH
44
TPU
40
LIGHT DRIVE
42
AMP
43
CARBON DIOXIDE SENSOR
24
AQUAMETRY SENSOR
26
PULSE OXIMETRY SENSOR
20
VENTILATOR
18
PATIENT
14

FIG. 2

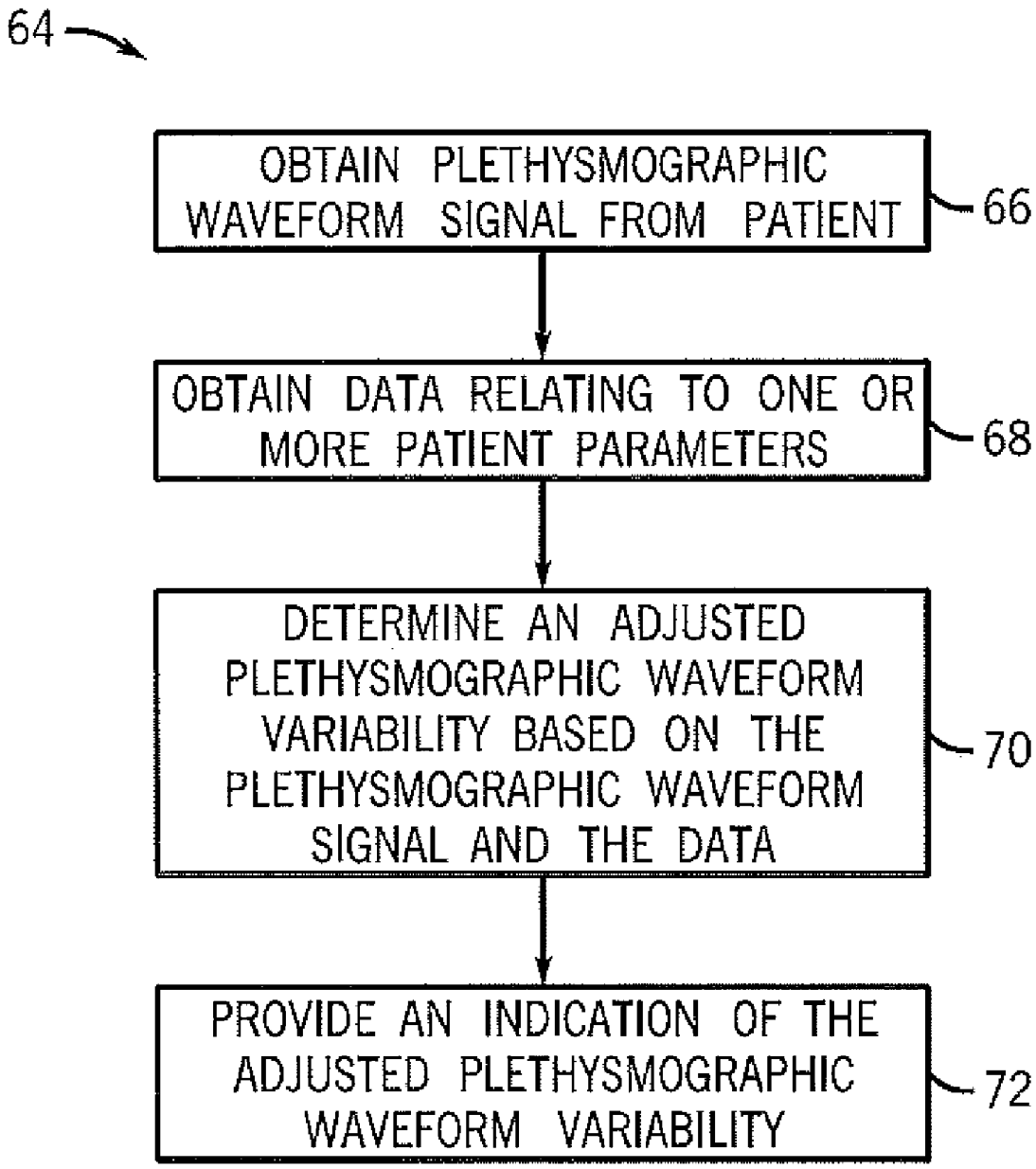

64
OBTAIN PLETHYSMOGRAPHIC WAVEFORM SIGNAL FROM PATIENT
66
OBTAIN DATA RELATING TO ONE OR MORE PATIENT PARAMETERS
68
DETERMINE AN ADJUSTED PLETHYSMOGRAPHIC WAVEFORM VARIABILITY BASED ON THE PLETHYSMOGRAPHIC WAVEFORM SIGNAL AND THE DATA
70
PROVIDE AN INDICATION OF THE ADJUSTED PLETHYSMOGRAPHIC WAVEFORM VARIABILITY
72

FIG. 3

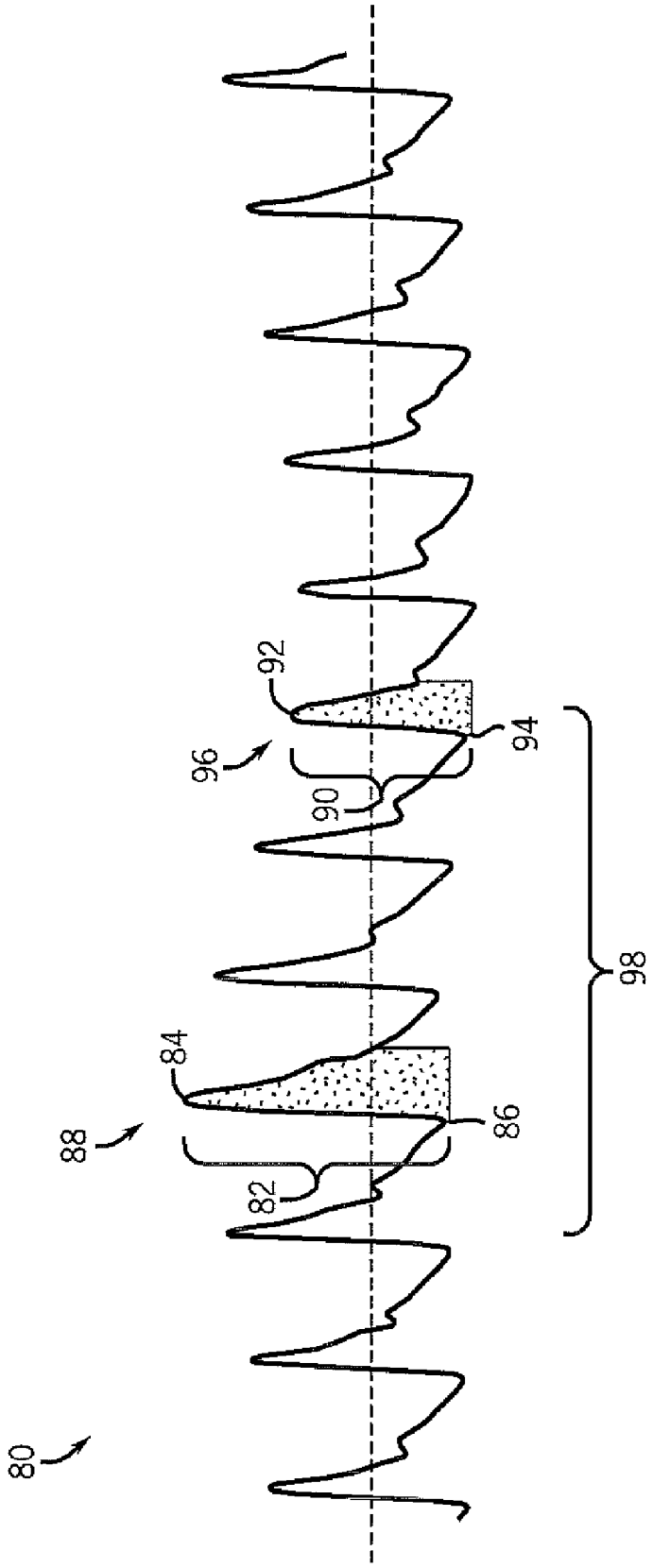


FIG. 4

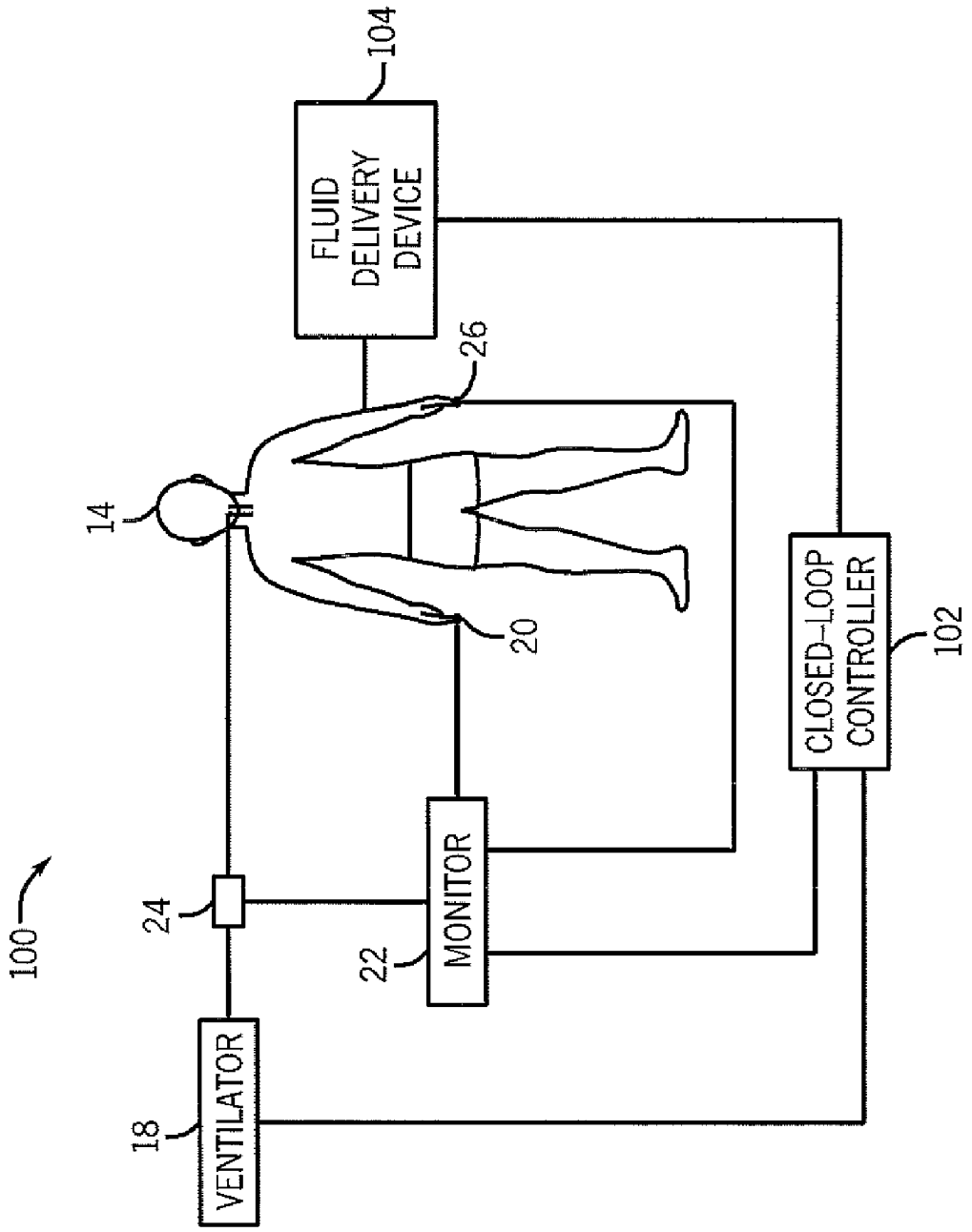

100
104
FLUID DELIVERY DEVICE
26
14
20
CLOSED-LOOP CONTROLLER
102
24
22
MONITOR
18
VENTILATOR

FIG. 5

MEDICAL DEVICE FOR ASSESSING INTRAVASCULAR BLOOD VOLUME AND TECHNIQUE FOR USING THE SAME

BACKGROUND

The present disclosure relates generally to a method and system for monitoring physiological parameters of a patient. Specifically, embodiments of the present invention relate to more accurate estimation of intravascular blood volume and fluid responsiveness by adjusting pulse oximetry waveform measurements to account for variations in respiratory parameters and/or other patient parameters.

This section is intended to introduce the reader to aspects of the art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

In the field of medicine, doctors often desire to monitor certain physiological characteristics of their patients. Accordingly, a wide variety of devices have been developed for monitoring many such characteristics of a patient. Such devices provide doctors and other healthcare personnel with the information they need to provide the best possible healthcare for their patients. As a result, such monitoring devices have become an indispensable part of modern medicine.

One physiological parameter that physicians may wish to monitor is blood fluid volume (i.e., intravascular volume). Variations from normal fluid volume in the blood may indicate a change in clinical condition or an injury. For example, hypovolemia is a state of decreased intravascular volume that may be associated with dehydration. Correct clinical assessment of hypovolemia is complex. More specifically, intravascular volume is difficult to estimate, particularly in critically ill patients. Without an accurate assessment of a patient's intravascular volume, it is difficult to predict whether a patient will respond to fluid therapy (e.g., a blood or fluid infusion) with an improvement in clinical condition, such as an increase in stroke volume and cardiac output. Accordingly, accurate assessments of intravascular volume may assist a clinician in determining whether a patient will be responsive to fluid therapy.

To this end, indicators such as the systolic blood pressure variation, pulse pressure variation, or stroke volume variation may be used to estimate intravascular volume and determine whether a patient is likely to be fluid responsive. However, these measurements tend to be invasive. For example, to obtain an accurate pulse pressure waveform from which the intravascular volume can be determined, a physician may insert an invasive arterial line.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the disclosure may become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. **1** is a block diagram of a ventilation system for determining intravascular blood volume in accordance with an embodiment;

FIG. **2** is a block diagram of a patient monitor that may be used in conjunction with the ventilation system of FIG. **1** in accordance with an embodiment;

FIG. **3** is a block diagram of a method illustrating an embodiment;

FIG. **4** is a plethysmographic waveform illustrating an embodiment; and

FIG. **5** is a block diagram of a closed-loop ventilation system for administering a fluid therapy in accordance with an embodiment.

DETAILED DESCRIPTION

One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions may be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

For patients who are undergoing multiple and overlapping medical treatments, monitoring physiological parameters may be complex. For example, certain physiological characteristics of the patient may be influenced by the medical treatment being provided. In embodiments, a ventilator may control a patient's breathing rate along with the type and amount of gases inhaled. Because respiration affects the delivery of oxygen from the lungs into the blood, changes in ventilation parameters and/or patient lung conditions may result in changes to hemodynamic parameters, such as pulse pressure and blood oxygenation.

The variability in a waveform representative of a patient's blood oxygen levels (i.e., a plethysmographic waveform) may be used to estimate a patient's intravascular volume. Blood oxygen levels may be monitored with a on-invasive, optical pulse oximetry sensor that transmits two or more wavelengths of light, most commonly red and near infrared wavelengths, through a patient's tissue and that photoelectrically detects the absorption and/or scattering of the transmitted light in such tissue. The use of pulse oximetry to estimate intravascular volume and fluid responsiveness in ventilated patients provides the ease of use of a noninvasive, rather than invasive, sensor. However, as noted, blood oxygen measurements may be affected by other clinical conditions, such as respiratory parameters. For example, the plethysmographic waveform signal may be sensitive to respiratory parameters, such as respiration rate, tidal volume, end tidal carbon dioxide concentration, or positive end-expiratory pressure, which may be controlled by particular settings on a ventilator. In addition, the plethysmographic waveform signal may be sensitive to tissue or blood constituent concentration, for example, a tissue water fraction or a partial pressure of carbon dioxide in the tissue. Further, the plethysmographic waveform signal may have certain patient-to-patient variability based on age, weight, gender, and clinical condition.

The plethysmographic waveform signal, or, in embodiments, a calculated value based on variation in the waveform signal, may be corrected or adjusted to provide a more accurate estimate of intravascular volume. A clinician may use the estimate of intravascular volume to make determinations about a patient's clinical condition, such as the likelihood that the patient will respond to fluid therapy. The adjustment may correct for certain physiological conditions that may influence the plethysmographic waveform and that may either mask or exaggerate the plethysmographic waveform variabil-

ity. For example, in the case of a ventilated patient with a controlled respiration rate, the patient's blood oxygen saturation may be higher relative to a patient who is not receiving breathing assistance. Depending on the patient's clinical condition, a ventilated patient with generally higher respiration rate may have greater peak-to-peak variability in a plethysmographic waveform, which in turn would result in a higher calculated variability value. Typically, higher variability values (e.g., greater than 15% variability) may be associated with increased fluid responsiveness. Accordingly, an artificially high variability value may mask a patient's true fluid responsiveness.

By correcting the variability of the plethysmographic signal to account for the influence of patient parameters, such as a higher respiration rate as a result of ventilation, the resulting plethysmographic waveform variability value may be more accurate. Accordingly, a clinician may be able to make more informed decisions about whether the patient may benefit from fluid therapy. In addition, the clinician may be able to assess changes in blood volume more rapidly and may be able to intervene to provide therapy to the patient at an earlier time point. In embodiments, a closed-loop system is provided in which the corrected plethysmographic waveform variability is used to estimate the intravascular volume and determine the fluid responsiveness of a patient. A closed-loop controller may control delivery of fluid therapy if the estimate of intravascular volume is associated with hypovolemia, which may indicate that the patient will be responsive to fluid therapy.

Embodiments provided herein are directed to medical devices for assessing intravascular volume based on respiratory or other patient parameters. Suitable devices may be incorporated into a respiratory system **10**, shown in FIG. **1**, or any other patient monitoring system. In one embodiment, the respiratory system **10** may include a tracheal tube **12**, such as an endotracheal tube, that is inserted into a patient **14** to deliver gases to and from the patient's lungs. The respiratory system **10** may also include a respiratory circuit **16** connecting the tracheal tube **12** to a ventilator **18**. In embodiments, the ventilator **18** may be a positive pressure ventilator, such as those available from Nellcor Puritan Bennett LLC.

The system **10** may also include a pulse oximetry sensor **20** for generating a plethysmographic waveform signal representative of a patient's blood oxygen levels. The pulse oximetry sensor **20** may be in communication with a monitor **22** configured to receive the plethysmographic waveform signal and estimate the patient's intravascular volume and/or fluid responsiveness. In one embodiment, the monitoring functions of the monitor **22** may be incorporated into a single device that also performs the functions of ventilator **18**.

In embodiments, the plethysmographic waveform variability may be corrected by adjusting for respiratory parameters controlled by the ventilator **18**. For example, the ventilator **18** may include a controller for controlling respiration rate, tidal volume, flow rate, pressure, peak airway pressure, ratio of expiration to inspiration time, fraction of inspired oxygen (i.e., the percentage of oxygen in the gas mixture), inspired pressure increases or decreases over each breath (e.g., positive end-expiratory pressure), and any other respiratory parameter. Any suitable respiratory parameter controlled by the ventilator **18** may be used to adjust an estimate of intravascular volume, as discussed in more detail below.

The respiratory system **10** may also include any number or combination of additional sensors for providing information related to patient parameters that may be used to correct or adjust the estimate of the patient's intravascular volume and/or fluid responsiveness. For example, suitable sensors may include sensors for determining tissue hydration, tissue constituents, blood constituents, blood pressure, heart rate, patient temperature, or tissue impedance. Such sensors may also include sensors for determining the presence or concentration of biomarkers, including sensors for circulating biomarkers related to cardiac stress and function (e.g., troponin or cholesterol) and/or biomarkers associated with lung function (e.g., surfactant protein D).

Suitable sensors for providing information about additional patient parameters may be optical, electrical, chemical, or biological sensors. A carbon dioxide sensor or tissue water fraction sensor may direct two or more wavelengths of light, most commonly near infrared wavelengths between about 1,000 nm to about 2,500 nm, into a sample, e.g., a gas sample or a tissue sample. Other sensors may include electrical sensors, such as electrical impedance sensors that may sense a voltage drop between two electrodes that are applied to a patient's tissue. Chemical sensors may include calorimetric chemical sensors, such as calorimetric sensors for detection of carbon dioxide. For example, a chemical sensor for carbon dioxide may include an indicator solution containing hydroxyl ions or amine residues that react chemically with carbon dioxide to form a carbonate and/or a bicarbonate or carbamate moiety, such as those discussed in co-pending U.S. Patent Publication No. 2008/0078394 by Ostrowski et al., filed on Sep. 25, 2006, the specification of which is incorporated by reference in its entirety herein for all purposes. This reaction may ultimately result in a color change that may be optically detected. Biological sensors may include enzymatic sensors for detecting a color or fluorescence change produced by enzymatic reactions or by antibody/ligand binding. For example, surfactant protein D may be detected by an enzyme-linked immunosorbent assay available from Cell Sciences (Canton, Mass.).

By way of example, FIG. **1** shows a carbon dioxide sensor **24** that may be associated with the respiratory circuit **16** and an aquametry sensor **26** that may be applied to an appropriate tissue location on the patient **14**. However, it should be understood that carbon dioxide sensor **24** and aquametry sensor **26** are merely illustrative of sensor types that may be used in conjunction with the respiratory system **10**. The carbon dioxide sensor **24** may be disposed along the respiratory circuit **16** (e.g., within a tube or connector of the respiratory circuit **16**) or associated with the respiratory circuit **16**. In addition, the carbon dioxide sensor **24** may be applied to a patient's tissue for determining partial pressure of carbon dioxide by optically interrogating the tissue. Carbon dioxide sensor **24** may be connected to downstream monitor **22** and may provide the data used to correct or adjust pulse oximetry variability measurements as provided herein. For example, a carbon dioxide sensor **24** may provide information to the monitor **22** relating to a carbon dioxide concentration in the expired gas stream. Carbon dioxide concentration measurements, e.g., capnography, may be used to estimate carbon dioxide partial pressure in arterial blood. In one embodiment, end-tidal CO_2 (the level of carbon dioxide released at the end of expiration) may be determined through capnography, which may be implemented by monitor **22**. In other embodiments, the capnography measurements may be performed by a separate processor-based device, or may be performed by the ventilator **18**. To coordinate the measurement of end-tidal CO_2 with the timing of the expiration, the ventilator **18** may provide information to the monitor **22** relating to the timing of the expiration and inhalation. For example, the respiration timing information may be used to control the carbon dioxide sensor **24**.

The respiratory system **10** may include, either instead of or in addition to carbon dioxide sensor/s **24**, any number of additional sensor types. For example, aquametry sensor **26**

may be a sensor that may be applied to a patient's tissue for determining a tissue water fraction. The aquametry sensor **26** may include any suitable arrangement of optical components for spectrophotometrically assessing the patient's tissue water fraction. In one embodiment, the aquametry sensor **26** and the pulse oximetry sensor **20** may be integrated into a unitary sensor body.

The downstream monitor **22** may receive signals, for example from ventilator **18** or from one or more sensors **24** or **26**, to correct or adjust pulse oximetry signals received from pulse oximetry sensor **20**. FIG. **2** is a block diagram of an embodiment of a monitor **22** that may be configured to implement the embodiments of the present disclosure. The pulse oximetry signal from the pulse oximetry sensor **20** may generate a plethysmographic waveform, which may be further processed and corrected by the monitor **22**. The monitor **22** may receive and further process a signal from carbon dioxide sensor **24** to determine a value representative of a concentration of carbon dioxide in the respiratory circuit **16** and/or a signal from aquametry sensor **26** to determine a value representative of a tissue water fraction of the patient.

The monitor **22** may include a microprocessor **32** coupled to an internal bus **34**. Also connected to the bus may be a RAM memory **36** and a display **38**. A time processing unit (TPU) **40** may provide timing control signals to light drive circuitry **42**, which controls when an optical sensor (e.g., pulse oximetry sensor **20**, carbon dioxide sensor **24**, or tissue water fraction sensor **26**) is activated, and, if multiple light sources are used, the multiplexed timing for the different light sources. TPU **40** may also control the gating-in of signals from sensor **20** through an amplifier **43** and a switching circuit **44**. These signals are sampled at the proper time, depending at least in part upon which of multiple light sources is activated, if multiple light sources are used. The received signal from the pulse oximetry sensor **20** may be passed through an amplifier **46**, a low pass filter **48**, and an analog-to-digital converter **50**. The digital data may then be stored in a queued serial module (QSM) **52**, for later downloading to RAM **36** or ROM **56** as QSM **52** fills up.

In an embodiment, based at least in part upon the received signals corresponding to the light received by optical components of the pulse oximetry sensor **20**, microprocessor **32** may calculate the oxygen saturation using various algorithms In addition, the microprocessor **32** may calculate a plethysmographic waveform variation using various algorithms, such as suitable statistical or time-series analysis algorithms. The plethysmograhpic waveform variation may be corrected based on input signals from other sensors (e.g., carbon dioxide sensor **24** or aquametry sensor **26**), the ventilator **18**, or caregiver inputs to control inputs **54**. For example, the caregiver may input a patient's age, weight, gender, or information about the patient's clinical condition that may be relevant to the accurate estimation of the intravascular volume. These algorithms may employ certain coefficients, which may be empirically determined, and may correspond to the wavelengths of light used. In addition, the algorithms may employ additional correction coefficients. By way of example, a particular end tidal carbon dioxide measurement, as generated from a signal provided by carbon dioxide sensor **24**, may be associated with a particular correction coefficient. The algorithms and coefficients may be stored in a ROM **56** or other suitable computer-readable storage medium and accessed and operated according to microprocessor **32** instructions. In one embodiment, the correction coefficients may be provided as a lookup table.

A patient's intravascular volume may be determined based on the corrected variability of a pulse oximetry plethysmographic waveform that is adjusted based on patient parameters. FIG. **3** is a process flow diagram illustrating a method **64** in accordance with some embodiments. The method may be performed as an automated procedure by a system, such as system **10**. In addition, certain steps of the method may be performed by a processor, or a processor-based device such as a patient monitor **22** that includes instructions for implementing certain steps of the method **64**.

According to an embodiment the method **64** begins with obtaining a plethystnographic waveform signal from a pulse oximetry sensor **20** at step **66**. Additional data relating to one or more patient parameters is obtained at step **68**. The data relating to one or more patient parameters may be received from the ventilator **18**, or may be calculated from signals received from patient sensors, e.g., carbon dioxide sensor **24** or aquametry sensor **26**. In addition, the data relating to one or more patient parameters may be manually input by a healthcare provider.

The monitor **22** may perform analysis of the plethysmographic waveform signal and calculation of the plethysmographic waveform variability at step **70** based on the plethysmographic waveform signal obtained at step **66** and the additional patient parameter data obtained at step **68**. The mathematical model for adjusting the waveform variability based on additional patient parameters obtained in step **68** may be linear or nonlinear, multivariate, partial least squares, principal component regression, auto-regressive moving average, mathematical curve fitting or simply an additive constant to the variability value. In one embodiment, the waveform variability is first calculated to provide a percentage value, and then the percentage value is adjusted based on the patient parameters.

In embodiments, the plethysmographic waveform signal may be modified or filtered based on the patient parameters prior to the calculation of the waveform variability to provide an adjusted or corrected variability value. For example, if a patient parameter is associated with having a damping effect on the waveform, the damping effect may be quantified and a filter may be used to remove the damping effect. In addition, the variability of the AC component (i.e., the pulsatile component) of the plethysmographic waveform signal, and not the DC component (i.e., the nonpulsatile component), may be used for assessing the intravascular blood volume. Accordingly, the DC component may be filtered out or otherwise removed from the waveform prior to the analysis in step **70**.

FIG. **4** illustrates a plethysmographic waveform **80** from which the plethysmographic waveform variability, W_v, may be determined based on the following equation:

$$W_v=(W_{max}-W_{min})/W_{mean}$$

where W_{max} is a maximum peak value, taken as a vertical distance **82** between a peak **84** and trough **86** for a largest peak **88** (i.e., a single cardiac cycle) and W_{min} is a minimum peak value, taken as vertical distance **90** between a peak **92** and trough **94** for a smallest peak **96** within a window **98** of consecutive peaks. W_{mean} represents the mean vertical distance between peak maxima and minima for the consecutive peaks in the window **98**. The window **98** may be a total number of peaks, such as 5 consecutive peaks, or may include all consecutive peaks within a time window, such as 10 seconds. In embodiments, an operator may adjust the settings on a monitor to change the size of the window according to the desired monitoring parameters. For example, an operator may increase the size of the window **98** from 10 seconds to 30 seconds to capture more data prior to providing the waveform variability. This may provide more accurate and/or stable

waveform variability values, but may also slow the updating. The monitor **22** may provide rolling updates as the window **98** moves forward in time.

Turning back to FIG. **3**, one or more patient parameters may be used to adjust or correct the calculated plethysmographic waveform variability at step **70**. In general, certain patient conditions may influence or have a correlative or inverse correlative relationship with the plethysmographic waveform. For example, the plethysmographic waveform variability may be particularly sensitive to vasoconstriction. In embodiments, the monitor **22** may allow a clinician to input information into the monitor related to whether or not the patient is taking any vasoconstrictive drugs, such as vasopressin analogs. Because vasoconstriction may increase cardiac preload and cardiac output, the resultant plethysmographic waveform may be adjusted to account for the effects of vasoconstrictive drugs. Similarly, certain clinical conditions may cause vasoconstriction, including stress and hypothermia. Accordingly, information from temperature sensors may provide information about whether or not vasoconstriction may be a factor in influencing the plethysmographic waveform variability. When patient parameters indicative of vasoconstriction are available, the plethysmographic waveform variability may be adjusted accordingly.

Similarly, information relating to whether or not a patient is receiving positive end expiratory pressure (PEEP) ventilation may be used to adjust the plethysmographic waveform variability. PEEP can cause significant hemodynamic consequences through decreasing venous return to the right heart and decreasing right ventricular function. PEEP may increase intrathoracic pressure, leading to a resulting decrease in venous return and decrease in cardiac output. Accordingly, information relating to PEEP may be used to adjust the plethysmographic waveform variability to a lower threshold value indicative of hypovolemia, as discussed below. For example, because PEEP and intravascular volume depletion may be contraindicated, a patient receiving PEEP may be closely monitored for hypovolemia and may have a lower plethysmograhpic waveform variability threshold. In addition, PEEP may lead to an increase in plethysmographic waveform variability, meaning that the plethysmographic waveform variability may be adjusted downwards to account for the effects of PEEP.

A patient parameter may also be used to determine if plethysmographic waveform variability is likely to be accurate for the patient in question. For example for patients with normal tidal volumes, e.g., between 8 and 15 kg/ml, the plethysmographic waveform variability value may be a generally accurate estimate of intravascular volume or fluid responsiveness. Accordingly, for these patients, the plethysmographic waveform variability value may not be adjusted when their tidal volumes are in the normal range. However, for patients outside of the range of normal tidal volumes, the plethysmographic waveform variability value may be less accurate and maybe adjusted according to its relationship with tidal volumes outside of normal ranges.

In embodiments, tissue water fraction information from an aquametry sensor **26** may be used to adjust the plethysmographic waveform variability. Because plethysmographic waveform variability may be used as a surrogate for blood volume, information about the hydration state of other compartments, such as the tissue, may provide additional information for assessing intravascular blood volume. Total body water depletion through dehydration may lead to poor intravascular volume. The body may protectively shunt blood towards the most vital organs (heart, kidney and brain) and away from peripheral organs such as the intestines, muscles and skin. Hence, the earliest sign of dehydration may be seen in the skin and muscle tissues. A reduced extracellular fluid volume, e.g., tissue water fraction, may be an early indicator of low intravascular volume. A tissue water fraction may be determined according to methods discussed in U.S. Patent Publication No. 2008/0221411 to Hausmann et al., filed on Mar. 9, 2007, the specification of which is incorporated by reference herein in its entirety for all purposes. If the tissue water fraction is associated with a low level of hydration, the plethysmographic waveform variability may be increased or adjusted upwards to reflect a higher likelihood of hypovolemia. In addition, the tissue water fraction may be used as a confirmation or confidence check for the plethysmographic waveform variability.

Further, information from a carbon dioxide sensor **24** may be used to adjust the plethysmographic waveform variability. Abnormally low levels of carbon dioxide in end tidal breaths may correlate with a concurrent decrease in blood volume. Accordingly, the plethysmographic waveform variability may be increased or adjusted upwards to reflect a higher likelihood of hypovolemia for patients with decreased end tidal carbon dioxide levels.

The monitor **22** may calculate the adjusted plethysmographic variability value and provide a display or other indication to a clinician, such as a graphical, visual, or audio representation of the intravascular volume at step **72**. For example, an adjusted plethysmographic variability value associated with normal intravascular blood volume may include a numeric value or a green light indicated on a display or a short tone generated by a speaker associated with monitor **22**. Similarly, an adjusted plethysmographic variability value associated with hypovolemia may trigger an alarm, which may include one or more of an audio or visual alarm indication. Further, the monitor **22** may provide a confidence metric or indicator to provide information to the clinician relating to how may parameters may have been taken into account. For example, if the plethysmographic variability value is consistent with trends from two or more additional patient parameters, the confidence may be higher than if only one patient parameter is used.

In one embodiment, the alarm may be triggered if the adjusted plethysmographic variability value is substantially greater than a predetermined value, substantially less than a predetermined value, or outside of a predetermined range. In one embodiment, a plethysmographic variability value of 10-15% may be considered to be indicative of a non-responsive or normovolemic patient that would not benefit from a fluid infusion. In addition, a plethysmographic variability value above 15% may be considered to be indicative of a hypovolemic patient that would likely benefit from a fluid infusion with respect to increasing cardiac output and improving the overall state of oxygenation. Accordingly, an alarm may be triggered when the plethysmographic waveform variability value is above 15% to alert a clinician that the patient may benefit from fluid therapy.

In other embodiments, a patient respiratory system **100** may operate under closed-loop control to provide to delivery of a fluid therapy (e.g., saline, blood, or other fluid) to a patient **14**. FIG. **5** shows a system **100** under control of a primary controller **102** that may include a closed-loop controller that cooperates with a monitor **22** to control delivery of fluid therapy to the patient **14**. The primary controller **102** may receive input from the monitor **22**. Based on the plethysmographic waveform signal from the pulse oximetry sensor **20** as well as additional patient parameter information, such as the settings of ventilator **18** or the inputs from additional patient sensors, the monitor **22** may calculate a plethysmographic waveform variability value. The plethysmographic waveform variability value may be used by the controller **102** to control the fluid delivery device **104**. It should be understood that while FIG. **5** depicts the controller **102** and the monitor **22** as separate devices, the monitoring functions of

monitor **22** and the controller functions of controller **102** may be incorporated into a single device in embodiments.

For example, the controller **102** may receive a request for increased fluid from the monitor **22** when a measured plethysmographic waveform variability value, adjusted with regard to available patient parameters, is above a predefined target, e.g., above 15%. The fluid delivery device **104** may include a peristaltic pump or other type of pump attached to an automatic intravenous line to achieve the desired delivery rate of the fluid to the patient. To control the rate at which the pump infuses the fluid, the speed of the pump may be controlled by the closed-loop controller **102**. When the plethysmographic waveform variability value falls below 15%, the controller **102** may slow or stop delivery of fluid from the fluid delivery device **104**. If the monitor **22** fails to determine that a plethysmographic waveform variability value has decreased after a set time, the controller **102** may generate a signal notifying a caregiver of prolonged hypovolemia or may cease delivery of fluids.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

What is claimed is:

1. A method, comprising:

using a processor:

receiving a plethysmographic waveform signal from a sensor, wherein the plethysmographic waveform signal is representative of a blood oxygen saturation of a patient;

receiving information related to a patient parameter that influences the plethysmographic waveform signal; and

determining a plethysmographic waveform variability based at least in part on the plethysmographic waveform signal; and

correcting the plethysmographic waveform variability to generate a corrected variability value based on the information related to the patient parameter, wherein the information related to the patient parameter comprises a tissue carbon dioxide level.

2. The method of claim **1**, comprising providing an indication of intravascular blood volume based on the corrected variability value.

3. The method of claim **1**, comprising triggering an alarm when the corrected variability value is greater than a predetermined level or outside of a predetermined range.

4. The method of claim **3**, wherein the predetermined level is 15%.

5. The method of claim **1**, wherein the information related to the patient parameter comprises a ventilator setting of positive end pressure ventilation, a tidal volume, a respiration rate, an end-tidal carbon dioxide level, or any combination thereof.

6. The method of claim **1**, wherein the information related to the patient parameter comprises a clinical condition of the patient or information related to a pharmacological treatment.

7. The method of claim **6**, wherein the clinical condition comprises a likelihood of vasoconstriction.

8. A monitor, comprising:

an input circuit configured to receive a plethysmographic waveform signal and information relating to a patient parameter that influences the plethysmographic waveform signal;

a memory storing an algorithm configured to calculate a corrected plethysmographic waveform variability based at least in part on the plethysmographic waveform signal and the information related to the patient parameter wherein the information relating to the patient parameter comprises information that the patient is undergoing positive end expiratory pressure ventilation, and wherein the algorithm is configured to increase the plethysmographic waveform variability based on the information; and

an output circuit configured to provide an indication of the corrected plethysmographic waveform variability.

9. The monitor of claim **8**, wherein the information relating to a patient parameter comprises information received from a carbon dioxide sensor or a tissue water fraction sensor.

10. The monitor of claim **8**, wherein the information relating to a patient parameter comprises respiratory parameter information.

11. The monitor of claim **8**, wherein the algorithm comprises the following equation:

$$W_v=(W_{max}-W_{min})/W_{mean},$$

wherein W_v is the plethysmographic waveform variability, W_{max} is a maximum peak value for a largest peak, W_{min} is a minimum peak value for a smallest peak, and W_{mean} represents the mean vertical distance between peak maxima and minima for the consecutive peaks in the window within a window of consecutive peaks.

12. The monitor of claim **8**, wherein the information related to the patient parameter comprises a tidal volume, and wherein the algorithm is configured to correct the plethysmographic waveform variability when the tidal volume is outside of a range of between 8 to 15 kg/ml.

13. The monitor of claim **8**, wherein the information relating to the patient parameter comprises information that the patient is receiving vasoconstrictive drugs, and wherein the algorithm is configured to adjust the plethysmographic waveform variability based on the information.

14. A method, comprising:

using a processor:

receiving a plethysmographic waveform signal from a sensor, wherein the plethysmographic waveform signal is representative of a blood oxygen saturation of a patient;

receiving information related to a patient parameter that influences the plethysmographic waveform signal; and

determining a plethysmographic waveform variability based at least in part on the plethysmographic waveform signal; and

correcting the plethysmographic waveform variability to generate a corrected variability value based on the information related to the patient parameter, wherein the information related to the patient parameter comprises a tissue water fraction.

15. The method of claim **14**, comprising providing an indication of intravascular blood volume based on the corrected variability value.

16. The method of claim **14**, comprising triggering an alarm when the corrected variability value is greater than a predetermined level or outside of a predetermined range.

17. The method of claim **16**, wherein the predetermined level is 15%.

18. The method of claim **14**, wherein the information related to the patient parameter comprises a ventilator setting of positive end pressure ventilation, a tidal volume, a respiration rate, an end-tidal carbon dioxide level, or any combination thereof.

* * * * *

专利名称(译)	用于评估血管内血容量的医疗设备和使用该设备的技术		
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[标]申请(专利权)人(译)	内尔科尔普里坦贝内特公司		
申请(专利权)人(译)	NELICOR PURITAN BENNETT LLC		
当前申请(专利权)人(译)	COVIDIEN LP		
[标]发明人	LOVEJOY DAVID		
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助理审查员(译)	雷迪SUNITA		
其他公开文献	US20100249559A1		
外部链接	Espacenet USPTO		

摘要(译)

本发明的实施例涉及用于确定患者的生理参数的系统和方法。具体地，本发明的实施例包括用于基于可能影响波形可变性的参数来校正脉搏血氧饱和度体积描记波形可变性测量的方法和系统。校正的测量值可用于估计患者的血管内血液量和/或液体反应性。