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Craig****(10) Patent No.: US 9,289,599 B2**
(45) Date of Patent: *Mar. 22, 2016**(54) VAGUS NERVE STIMULATION METHOD****(75) Inventor:** Arthur D. Craig, Phoenix, AZ (US)**(73) Assignee:** DIGNITY HEALTH, Phoenix, AZ (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.

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Related U.S. Application Data**(63)** Continuation of application No. 11/693,421, filed on Mar. 29, 2007, now Pat. No. 8,150,508.**(60)** Provisional application No. 60/787,680, filed on Mar. 29, 2006.**(51) Int. Cl.****A61N 1/372** (2006.01)**A61N 1/05** (2006.01)

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See application file for complete search history.**(56) References Cited****U.S. PATENT DOCUMENTS**3,760,812 A 9/1973 Timm et al.
3,796,221 A 3/1974 Hagfors

(Continued)

FOREIGN PATENT DOCUMENTSAU 2012202405 A1 5/2012
AU 2012202408 A1 5/2012

(Continued)

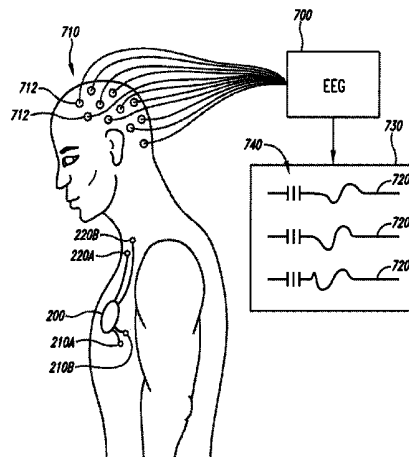
OTHER PUBLICATIONS

Bachman, et al., "Effects of Vagal Volleys and Serotonin on Units of Cingulate Cortex in Monkeys," Brian Research, vol. 130 (1997) (pp. 253-269).

(Continued)

Primary Examiner — Deborah Malamud**(74) Attorney, Agent, or Firm** — Stephen Eisenmann**(57)****ABSTRACT**

An implanted electrical signal generator delivers a novel exogenous electrical signal to a vagus nerve of a patient. The vagus nerve conducts action potentials originating in the heart and lungs to various structures of the brain, thereby eliciting a vagal evoked potential in those structures. The exogenous electrical signal simulates and/or augments the endogenous afferent activity originating from the heart and/or lungs of the patient, thereby enhancing the vagal evoked potential in the various structures of the brain. The exogenous electrical signal includes a series of electrical pulses organized or patterned into a series of microbursts including 2 to 20 pulses each. No pulses are sent between the microbursts. Each of the microbursts may be synchronized with the QRS wave portion of an ECG. The enhanced vagal evoked potential in the various structures of the brain may be used to treat various medical conditions including epilepsy and depression.

35 Claims, 10 Drawing Sheets

(51)	Int. Cl.		5,690,688 A	11/1997	Noren et al.
	<i>A61N 1/36</i> (2006.01)		5,690,691 A	11/1997	Chen et al.
	<i>A61B 5/0476</i> (2006.01)		5,700,282 A	12/1997	Zabara
	<i>A61B 5/00</i> (2006.01)		5,702,428 A	12/1997	Tippey et al.
(52)	U.S. Cl.		5,702,429 A	12/1997	King
	CPC <i>A61N1/36114</i> (2013.01); <i>A61N 1/36139</i>		5,707,400 A	1/1998	Terry, Jr. et al.
	(2013.01); <i>A61N 1/36178</i> (2013.01); <i>A61B</i>		5,755,750 A	5/1998	Petruska et al.
	<i>5/0476</i> (2013.01); <i>A61B 5/4094</i> (2013.01)		5,792,212 A	8/1998	Weijand
			5,800,474 A	9/1998	Benabid et al.
			5,814,092 A	9/1998	King
			5,836,994 A	11/1998	Bourgeois
			5,861,014 A	1/1999	Familoni
			5,913,882 A	6/1999	King
			5,916,239 A	6/1999	Geddes et al.
			5,928,272 A	7/1999	Adkins et al.
			5,941,906 A	8/1999	Barreras, Sr. et al.
			5,995,868 A	11/1999	Dorfmeister et al.
			6,002,966 A	12/1999	Loeb et al.
			6,016,449 A	1/2000	Fischell et al.
			6,041,258 A	3/2000	Cigaina et al.
(56)	References Cited		6,073,048 A *	6/2000	Kieval et al. 607/17
	U.S. PATENT DOCUMENTS		6,083,249 A	7/2000	Familoni
	4,073,048 A	2/1978 Ditcher	6,101,412 A	8/2000	Duhaylongsod
	4,107,469 A	8/1978 Jenkins	6,104,955 A	8/2000	Bourgeois
	4,305,402 A	12/1981 Katims	6,104,959 A	8/2000	Spertell
	4,338,945 A	7/1982 Kosugi et al.	6,115,628 A	9/2000	Stadler et al.
	4,424,812 A	1/1984 Lesnick	6,132,361 A	10/2000	Epstein et al.
	4,431,000 A	2/1984 Butler et al.	6,141,590 A	10/2000	Renirie et al.
	4,459,989 A	7/1984 Borkan	6,161,044 A	12/2000	Silverstone
	4,503,863 A	3/1985 Katims	6,167,311 A	12/2000	Rezai
	4,509,946 A	4/1985 McFarlane	6,175,764 B1	1/2001	Loeb et al.
	4,541,432 A	9/1985 Molina-Negro et al.	6,188,929 B1	2/2001	Giordano
	4,573,481 A	3/1986 Bullara	6,219,580 B1	4/2001	Faltys et al.
	4,577,316 A	3/1986 Schiff	6,221,908 B1	4/2001	Kilgard et al.
	4,590,946 A	5/1986 Loeb	6,238,423 B1	5/2001	Bardy
	4,592,339 A	6/1986 Kuzmak et al.	6,249,704 B1	6/2001	Maltan et al.
	4,606,349 A	8/1986 Livingston et al.	6,253,109 B1	6/2001	Gielen
	4,608,985 A	9/1986 Crish et al.	6,266,564 B1	7/2001	Hill et al.
	4,612,934 A	9/1986 Borkan	6,269,270 B1	7/2001	Boveja
	4,625,308 A	11/1986 Kim et al.	6,295,472 B1	9/2001	Rubinstein et al.
	4,628,942 A	12/1986 Sweeney et al.	6,304,775 B1	10/2001	Iasemidis et al.
	4,649,936 A	3/1987 Ungar et al.	6,308,102 B1	10/2001	Sieracki et al.
	4,702,254 A	10/1987 Zabara	6,324,421 B1	11/2001	Stadler et al.
	4,793,353 A	12/1988 Borkan	6,327,503 B1	12/2001	Familoni
	4,867,164 A	9/1989 Zabara	6,339,725 B1	1/2002	Naritoku et al.
	4,920,979 A	5/1990 Bullara	6,341,236 B1	1/2002	Osorio et al.
	4,949,721 A	8/1990 Toriu et al.	6,353,762 B1	3/2002	Baudino et al.
	4,977,895 A	12/1990 Tannenbaum	6,356,788 B2	3/2002	Boveja
	4,979,511 A	12/1990 Terry, Jr.	6,358,203 B2	3/2002	Bardy
	5,025,807 A	6/1991 Zabara	6,366,813 B1	4/2002	DiLorenzo
	5,073,048 A	12/1991 Adachi et al.	6,366,814 B1	4/2002	Boveja et al.
	5,081,987 A	1/1992 Nigam	6,374,140 B1	4/2002	Rise
	5,150,508 A	9/1992 St. Denis	6,381,493 B1	4/2002	Stadler et al.
	5,154,172 A	10/1992 Terry, Jr. et al.	6,381,496 B1	4/2002	Meadows et al.
	5,179,950 A	1/1993 Stanislaw	6,381,499 B1	4/2002	Taylor et al.
	5,186,170 A	2/1993 Varrichio et al.	6,418,344 B1	7/2002	Rezai et al.
	5,188,104 A	2/1993 Wernicke et al.	6,425,852 B1	7/2002	Epstein et al.
	5,205,285 A	4/1993 Baker, Jr.	6,438,423 B1	8/2002	Rezai et al.
	5,215,086 A	6/1993 Terry, Jr. et al.	6,449,512 B1	9/2002	Boveja
	5,222,494 A	6/1993 Baker, Jr.	6,453,199 B1	9/2002	Kobozev
	5,231,988 A	8/1993 Wernicke et al.	6,459,936 B2	10/2002	Fischell et al.
	5,235,980 A	8/1993 Varrichio et al.	6,463,328 B1	10/2002	John
	5,263,480 A	11/1993 Wernicke et al.	6,466,822 B1	10/2002	Pless
	5,269,303 A	12/1993 Wernicke et al.	6,473,639 B1	10/2002	Fischell et al.
	5,299,569 A	4/1994 Wernicke et al.	6,473,644 B1	10/2002	Terry, Jr. et al.
	5,304,206 A	4/1994 Baker, Jr. et al.	6,477,417 B1	11/2002	Levine
	5,330,507 A	7/1994 Schwartz	6,477,418 B2	11/2002	Plicchi et al.
	5,330,515 A	7/1994 Rutecki et al.	6,480,743 B1	11/2002	Kirkpatrick et al.
	5,334,221 A	8/1994 Bardy	6,484,132 B1	11/2002	Hively et al.
	5,335,657 A	8/1994 Terry, Jr. et al.	6,487,446 B1	11/2002	Hill et al.
	5,354,320 A	10/1994 Schaldach et al.	6,505,074 B2	1/2003	Boveja et al.
	5,411,531 A	5/1995 Hill et al.	6,522,928 B2	2/2003	Whitehurst et al.
	5,411,540 A	5/1995 Edell et al.	6,532,388 B1	3/2003	Hill et al.
	5,423,872 A	6/1995 Cigaina et al.	6,549,804 B1	4/2003	Osorio et al.
	5,507,784 A	4/1996 Hill et al.	6,556,868 B2	4/2003	Naritoku et al.
	5,522,862 A	6/1996 Testerman et al.	6,564,102 B1	5/2003	Boveja
	5,522,865 A	6/1996 Schulman et al.	6,565,503 B2	5/2003	Leysieffer et al.
	5,540,730 A	7/1996 Terry, Jr. et al.	6,579,280 B1	6/2003	Kovach et al.
	5,540,734 A	7/1996 Zabara	6,587,719 B1	7/2003	Barrett et al.
	5,571,150 A	11/1996 Wernicke et al.			
	5,601,617 A	2/1997 Loeb et al.			
	5,611,350 A	3/1997 John			
	5,645,570 A	7/1997 Corbucci			
	5,651,378 A	7/1997 Matheny et al.			
	5,658,318 A	8/1997 Stroetmann et al.			
	5,690,681 A	11/1997 Geddes et al.			

(56)

References Cited

U.S. PATENT DOCUMENTS

6,587,724 B2	7/2003	Mann	7,149,574 B2	12/2006	Yun et al.
6,587,726 B2	7/2003	Lurie et al.	7,164,941 B2	1/2007	Misczynski et al.
6,587,727 B2	7/2003	Osorio et al.	7,167,750 B2	1/2007	Knudson et al.
6,591,138 B1	7/2003	Fischell et al.	7,177,678 B1	2/2007	Osorio et al.
6,594,524 B2	7/2003	Esteller et al.	7,184,837 B2	2/2007	Goetz
6,600,953 B2	7/2003	Flesler et al.	7,188,053 B2	3/2007	Nikitin et al.
6,609,025 B2	8/2003	Barrett et al.	7,191,012 B2	3/2007	Boveja et al.
6,609,030 B1	8/2003	Rezai et al.	7,204,833 B1	4/2007	Osorio et al.
6,609,031 B1	8/2003	Law et al.	7,209,787 B2	4/2007	DiLorenzo
6,610,713 B2	8/2003	Tracey	7,209,790 B2	4/2007	Thompson et al.
6,611,715 B1	8/2003	Boveja	7,231,254 B2	6/2007	DiLorenzo
6,612,983 B1	9/2003	Marchal	7,236,822 B2	6/2007	Dobak, III
6,615,081 B1	9/2003	Boveja	7,236,830 B2	6/2007	Gliner
6,615,084 B1	9/2003	Cigaina	7,236,831 B2	6/2007	Firlik et al.
6,615,085 B1	9/2003	Boveja	7,239,912 B2	7/2007	Dobak, III
6,622,038 B2	9/2003	Barrett et al.	7,239,926 B2	7/2007	Goetz
6,622,041 B2	9/2003	Terry, Jr. et al.	7,242,983 B2	7/2007	Frei et al.
6,622,047 B2	9/2003	Barrett et al.	7,242,984 B2	7/2007	DiLorenzo
6,628,987 B1	9/2003	Hill et al.	7,249,281 B2	7/2007	Shirley et al.
6,631,293 B2	10/2003	Lyden	7,252,090 B2	8/2007	Goetz
6,656,125 B2	12/2003	Misczynski et al.	7,254,439 B2	8/2007	Misczynski et al.
6,656,960 B2	12/2003	Puskas	7,263,405 B2	8/2007	Boveja et al.
6,662,053 B2	12/2003	Borkan	7,277,758 B2	10/2007	DiLorenzo
6,668,191 B1	12/2003	Boveja	7,277,761 B2	10/2007	Shelchuk
6,671,547 B2	12/2003	Lyster et al.	7,289,545 B2	10/2007	Charles
6,671,555 B2	12/2003	Gielen et al.	7,289,844 B2	10/2007	Misczynski et al.
6,671,556 B2	12/2003	Osorio et al.	7,292,890 B2	11/2007	Whitehurst et al.
6,684,104 B2	1/2004	Gordon et al.	7,299,091 B2	11/2007	Barrett et al.
6,684,105 B2	1/2004	Cohen et al.	7,321,793 B2	1/2008	Ben Ezra et al.
6,690,973 B2	2/2004	Hill et al.	7,340,302 B1	3/2008	Falkenberg et al.
6,690,974 B2	2/2004	Archer et al.	7,340,306 B2	3/2008	Barrett et al.
6,708,064 B2	3/2004	Rezai	7,346,395 B2	3/2008	Lozano et al.
6,721,603 B2	4/2004	Zabara et al.	7,352,285 B2	4/2008	Sakama et al.
6,731,979 B2	5/2004	MacDonald	7,363,076 B2	4/2008	Yun et al.
6,731,986 B2	5/2004	Mann	7,369,897 B2	5/2008	Boveja et al.
6,737,875 B2	5/2004	Davis et al.	7,377,930 B2	5/2008	Loughran
6,754,530 B2	6/2004	Bakels et al.	7,395,117 B2	7/2008	Mazar et al.
6,754,536 B2	6/2004	Swoyer et al.	7,418,292 B2	8/2008	Shafer
6,760,626 B1	7/2004	Boveja	7,422,255 B2	9/2008	Hess
6,764,498 B2	7/2004	Mische	7,422,555 B2	9/2008	Zabara
6,768,969 B1	7/2004	Nikitin et al.	7,437,196 B2	10/2008	Wyller et al.
6,775,573 B2	8/2004	Schuler et al.	7,444,183 B2	10/2008	Knudson et al.
6,788,975 B1	9/2004	Whitehurst et al.	7,444,184 B2	10/2008	Boveja et al.
6,793,670 B2	9/2004	Osorio et al.	7,454,245 B2	11/2008	Armstrong et al.
6,819,956 B2	11/2004	DiLorenzo	7,454,251 B2	11/2008	Rezai et al.
6,825,767 B2	11/2004	Humbard	7,454,359 B2	11/2008	Rosenfeld et al.
6,826,428 B1	11/2004	Chen et al.	7,483,743 B2	1/2009	Mann et al.
6,832,114 B1	12/2004	Whitehurst et al.	7,483,747 B2	1/2009	Gliner et al.
6,843,870 B1	1/2005	Bluger	7,485,095 B2	2/2009	Shusterman
6,853,862 B1	2/2005	Marchal et al.	7,493,168 B2	2/2009	Rezai
6,885,888 B2	4/2005	Rezai	7,496,409 B2	2/2009	Greenhut et al.
6,895,278 B1	5/2005	Gordon	7,509,170 B2	3/2009	Zhang et al.
6,900,421 B2	5/2005	Varma	7,512,438 B2	3/2009	Fischell et al.
6,901,292 B2	5/2005	Hrdlicka et al.	7,519,430 B2	4/2009	Von Arx et al.
6,901,293 B2	5/2005	Rogers et al.	7,532,938 B2	5/2009	Machado et al.
6,904,390 B2	6/2005	Nikitin et al.	7,541,191 B2	6/2009	Duic
6,907,295 B2	6/2005	Gross et al.	7,542,800 B2	6/2009	Libbus et al.
6,920,357 B2	7/2005	Osorio et al.	7,547,284 B2	6/2009	Brainard, II
6,934,580 B1	8/2005	Osorio et al.	7,551,958 B2	6/2009	Libbus et al.
6,940,255 B2	9/2005	Loch	7,561,921 B2	7/2009	Phillips et al.
6,944,501 B1	9/2005	Pless	7,565,199 B2	7/2009	Sheffield et al.
6,949,929 B2	9/2005	Gray et al.	7,565,200 B2	7/2009	Wyller et al.
6,958,705 B2	10/2005	Lebel et al.	7,577,481 B2	8/2009	Firlik et al.
6,961,618 B2	11/2005	Osorio et al.	7,596,413 B2	9/2009	Libbus et al.
7,006,859 B1	2/2006	Osorio et al.	7,601,115 B2	10/2009	Riehl
7,006,872 B2	2/2006	Gielen et al.	7,603,174 B2	10/2009	De Ridder
7,050,856 B2	5/2006	Stypulkowski	7,606,622 B2	10/2009	Reeve
7,052,983 B2	5/2006	Park et al.	7,610,083 B2	10/2009	Drew et al.
7,054,686 B2	5/2006	MacDonald	7,613,515 B2	11/2009	Knudson et al.
7,076,307 B2	7/2006	Boveja et al.	7,617,002 B2	11/2009	Goetz
7,085,605 B2	8/2006	Bluger et al.	7,620,455 B2	11/2009	Maschino
7,091,231 B2	8/2006	Donde et al.	7,620,456 B2	11/2009	Gliner et al.
7,107,097 B2	9/2006	Stern et al.	7,623,926 B2	11/2009	Rossing et al.
7,142,923 B2	11/2006	North et al.	7,623,927 B2	11/2009	Rezai
7,146,217 B2	12/2006	Firlik et al.	7,623,928 B2	11/2009	DiLorenzo
			7,624,293 B2	11/2009	Osorio et al.
			7,630,757 B2	12/2009	Dorfmeister et al.
			7,630,773 B2	12/2009	Seeberger et al.
			7,634,317 B2	12/2009	Ben-David et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,640,063 B2	12/2009	Rezai et al.	8,108,046 B2	1/2012	Giftakis et al.
7,643,293 B2	1/2010	Chu	8,108,048 B2	1/2012	Masoud
7,661,933 B2	2/2010	Ohya et al.	8,111,150 B2	2/2012	Miller et al.
7,672,730 B2	3/2010	Firlik et al.	8,112,148 B2	2/2012	Giftakis et al.
7,672,733 B2	3/2010	Zhou et al.	8,112,153 B2	2/2012	Giftakis et al.
7,676,263 B2	3/2010	Harris et al.	8,123,668 B2	2/2012	Annest et al.
7,684,866 B2	3/2010	Fowler et al.	8,126,529 B2	2/2012	Johnson et al.
7,685,005 B2	3/2010	Riff et al.	8,126,568 B2	2/2012	Gliner
7,689,276 B2	3/2010	Dobak	8,137,269 B2	3/2012	Sheikhzadeh-Nadjar et al.
7,697,991 B2	4/2010	Machado et al.	8,150,508 B2	4/2012	Craig
7,697,993 B2	4/2010	Gilkerson et al.	8,155,742 B2	4/2012	Ball et al.
7,706,866 B2	4/2010	Zhang et al.	8,165,682 B2	4/2012	Gopalsami et al.
7,715,919 B2	5/2010	Osorio et al.	8,170,668 B2	5/2012	Ettori et al.
7,715,924 B2	5/2010	Rezai et al.	8,175,705 B2	5/2012	Libbus
7,725,196 B2	5/2010	Machado et al.	8,187,181 B2	5/2012	Osorio et al.
7,729,773 B2	6/2010	Sloan	8,209,009 B2	6/2012	Giftakis et al.
7,742,820 B2	6/2010	Wyler et al.	8,209,018 B2	6/2012	Osorio et al.
7,747,325 B2	6/2010	Dilorenzo	8,211,033 B2	7/2012	Siejko et al.
7,747,551 B2	6/2010	Snyder	8,214,043 B2	7/2012	Matos
7,756,584 B2	7/2010	Sheffield et al.	8,219,188 B2	7/2012	Craig
7,761,145 B2	7/2010	Virag et al.	8,280,505 B2	10/2012	Craig
7,764,988 B2	7/2010	Drew et al.	2001/0034541 A1	10/2001	Lyden
7,769,465 B2	8/2010	Matos	2001/0037220 A1	11/2001	Merry et al.
7,778,704 B2	8/2010	Rezai	2002/0052539 A1	5/2002	Haller et al.
7,778,711 B2	8/2010	Ben-David et al.	2002/0065509 A1	5/2002	Lebel et al.
7,783,349 B2	8/2010	Libbus et al.	2002/0072782 A1	6/2002	Osorio et al.
7,801,611 B2	9/2010	Persen et al.	2002/0082480 A1	6/2002	Riff et al.
7,805,199 B2	9/2010	KenKnight et al.	2002/0099412 A1	7/2002	Fischell et al.
7,831,301 B2	11/2010	Webb et al.	2002/0099417 A1	7/2002	Naritoku et al.
7,831,305 B2	11/2010	Gliner	2002/0116030 A1	8/2002	Rezai
7,831,308 B2	11/2010	Rezai et al.	2002/0120310 A1	8/2002	Linden et al.
7,832,305 B2	11/2010	Mahendra et al.	2002/0133204 A1	9/2002	Hrdlicka et al.
7,833,174 B2	11/2010	Rezai et al.	2002/0143368 A1	10/2002	Bakels et al.
7,835,796 B2	11/2010	Maschino et al.	2002/0151939 A1	10/2002	Rezai
7,844,334 B2	11/2010	Maile et al.	2002/0153901 A1	10/2002	Davis et al.
7,844,338 B2	11/2010	Knudson et al.	2002/0188214 A1	12/2002	Misczynski et al.
7,853,329 B2	12/2010	DiLorenzo	2003/0028226 A1	2/2003	Thompson et al.
7,856,264 B2	12/2010	Firlik et al.	2003/0036780 A1	2/2003	Barrett et al.
7,856,272 B2	12/2010	Nikitin et al.	2003/0040774 A1	2/2003	Terry et al.
7,865,237 B2	1/2011	Machado et al.	2003/0055457 A1	3/2003	MacDonald
7,885,709 B2	2/2011	Ben-David	2003/0074032 A1	4/2003	Gliner
7,889,069 B2	2/2011	Fifolt et al.	2003/0083716 A1	5/2003	Nicolelis et al.
7,890,159 B2	2/2011	Zhang et al.	2003/0088274 A1	5/2003	Gliner et al.
7,890,185 B2	2/2011	Cohen et al.	2003/0095648 A1	5/2003	Kaib et al.
7,899,540 B2	3/2011	Maschino et al.	2003/0097161 A1	5/2003	Firlik et al.
7,904,161 B2	3/2011	Osypka	2003/0109903 A1	6/2003	Berrang et al.
7,908,009 B2	3/2011	Wyler et al.	2003/0125786 A1	7/2003	Gliner et al.
7,912,537 B2	3/2011	Lee et al.	2003/0130706 A1	7/2003	Sheffield et al.
7,917,206 B2	3/2011	Frei et al.	2003/0144709 A1	7/2003	Zabara et al.
7,917,225 B2	3/2011	Wyler et al.	2003/0144711 A1	7/2003	Pless et al.
7,930,035 B2	4/2011	DiLorenzo	2003/0144829 A1	7/2003	Geatz et al.
7,933,646 B2	4/2011	Frei et al.	2003/0181954 A1	9/2003	Rezai
7,945,316 B2	5/2011	Giftakis et al.	2003/0181958 A1	9/2003	Dobak
7,945,333 B2	5/2011	Jacobson	2003/0181959 A1	9/2003	Dobak
7,949,401 B2	5/2011	Fowler et al.	2003/0195574 A1	10/2003	Osorio et al.
7,949,404 B2	5/2011	Hill	2003/0208212 A1	11/2003	Cigaina
7,962,218 B2	6/2011	Balzer et al.	2003/0210147 A1	11/2003	Humbar
7,962,220 B2	6/2011	Kolafa et al.	2003/0212440 A1	11/2003	Boveja
7,974,693 B2	7/2011	Ben-David et al.	2003/0236558 A1	12/2003	Whitehurst et al.
7,979,137 B2	7/2011	Tracey et al.	2004/0006278 A1	1/2004	Webb et al.
7,983,759 B2	7/2011	Stahmann et al.	2004/0015205 A1	1/2004	Whitehurst et al.
7,986,997 B2	7/2011	Elsner et al.	2004/0024428 A1	2/2004	Barrett et al.
7,991,625 B2	8/2011	Rosenfeld et al.	2004/0036377 A1	2/2004	Mezinis
8,014,865 B2	9/2011	Najafi et al.	2004/0039424 A1	2/2004	Merritt et al.
8,036,736 B2	10/2011	Snyder et al.	2004/0039427 A1	2/2004	Barrett et al.
8,041,419 B2	10/2011	Giftakis et al.	2004/0088024 A1	5/2004	Firlik et al.
8,046,069 B2	10/2011	Kramer et al.	2004/0111139 A1	6/2004	McCreery
8,046,075 B2	10/2011	Rezai	2004/0112894 A1	6/2004	Varma
8,050,767 B2	11/2011	Sheffield et al.	2004/0122484 A1	6/2004	Hatlestad et al.
8,065,011 B2	11/2011	Echaz et al.	2004/0122485 A1	6/2004	Stahmann et al.
8,065,012 B2	11/2011	Firlik et al.	2004/0122489 A1	6/2004	Mazar et al.
8,068,918 B2	11/2011	Vallapureddy et al.	2004/0133119 A1	7/2004	Osorio et al.
8,096,954 B2	1/2012	Stahmann et al.	2004/0138516 A1	7/2004	Osorio et al.
8,108,033 B2	1/2012	Drew et al.	2004/0138517 A1	7/2004	Osorio et al.
8,108,038 B2	1/2012	Giftakis et al.	2004/0138518 A1	7/2004	Rise et al.
			2004/0138647 A1	7/2004	Osorio et al.
			2004/0138711 A1	7/2004	Osorio et al.
			2004/0138721 A1	7/2004	Osorio et al.
			2004/0147969 A1	7/2004	Mann et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2004/0147992 A1	7/2004	Bluger et al.	2005/0131493 A1	6/2005	Boveja et al.
2004/0153129 A1	8/2004	Pless et al.	2005/0131506 A1	6/2005	Rezai et al.
2004/0158119 A1	8/2004	Osorio et al.	2005/0137480 A1	6/2005	Alt et al.
2004/0158165 A1	8/2004	Yonce et al.	2005/0143781 A1	6/2005	Carbunaru et al.
2004/0167583 A1	8/2004	Knudson et al.	2005/0143786 A1	6/2005	Boveja
2004/0167587 A1	8/2004	Thompson	2005/0148893 A1	7/2005	Misczynski et al.
2004/0172085 A1	9/2004	Knudson et al.	2005/0148894 A1	7/2005	Misczynski et al.
2004/0172088 A1	9/2004	Knudson et al.	2005/0148895 A1	7/2005	Misczynski et al.
2004/0172089 A1	9/2004	Whitehurst et al.	2005/0153885 A1	7/2005	Yun et al.
2004/0172091 A1	9/2004	Rezai	2005/0154425 A1	7/2005	Boveja et al.
2004/0172094 A1	9/2004	Cohen et al.	2005/0154435 A1	7/2005	Stern et al.
2004/0176812 A1	9/2004	Knudson et al.	2005/0159789 A1	7/2005	Brockway et al.
2004/0176831 A1	9/2004	Gliner et al.	2005/0161052 A1	7/2005	Rezai et al.
2004/0193231 A1	9/2004	David et al.	2005/0165458 A1	7/2005	Boveja et al.
2004/0199146 A1	10/2004	Rogers et al.	2005/0177192 A1	8/2005	Rezai et al.
2004/0199187 A1	10/2004	Loughran	2005/0177200 A1	8/2005	George et al.
2004/0199210 A1	10/2004	Shelchuk	2005/0177206 A1	8/2005	North et al.
2004/0199212 A1	10/2004	Fischell et al.	2005/0182389 A1	8/2005	LaPorte et al.
2004/0210270 A1	10/2004	Erickson	2005/0187590 A1	8/2005	Boveja et al.
2004/0210274 A1	10/2004	Bauhahn et al.	2005/0187593 A1	8/2005	Housworth et al.
2004/0249302 A1	12/2004	Donoghue et al.	2005/0187796 A1	8/2005	Rosenfeld et al.
2004/0254612 A1	12/2004	Ezra et al.	2005/0192644 A1	9/2005	Boveja et al.
2004/0254616 A1 *	12/2004	Rossing et al. 607/42	2005/0197675 A1	9/2005	David et al.
2004/0260346 A1	12/2004	Overall et al.	2005/0222631 A1	10/2005	Dalal et al.
2004/0263172 A1	12/2004	Gray et al.	2005/0228693 A1	10/2005	Webb et al.
2005/0004615 A1	1/2005	Sanders	2005/0240246 A1	10/2005	Lee et al.
2005/0004621 A1	1/2005	Boveja et al.	2005/0245944 A1	11/2005	Rezai
2005/0010262 A1	1/2005	Rezai et al.	2005/0245971 A1	11/2005	Brockway et al.
2005/0015128 A1	1/2005	Rezai et al.	2005/0245990 A1	11/2005	Roberson
2005/0016657 A1	1/2005	Bluger	2005/0251220 A1	11/2005	Barrett et al.
2005/0020887 A1	1/2005	Goldberg	2005/0251222 A1	11/2005	Barrett et al.
2005/0021092 A1	1/2005	Yun et al.	2005/0261542 A1	11/2005	Riehl
2005/0021103 A1	1/2005	DiLorenzo	2005/0267550 A1	12/2005	Hess et al.
2005/0021104 A1	1/2005	DiLorenzo	2005/0272280 A1	12/2005	Osyppka
2005/0021105 A1	1/2005	Firlik et al.	2005/0277872 A1	12/2005	Colby et al.
2005/0021106 A1	1/2005	Firlik et al.	2005/0277998 A1	12/2005	Tracey et al.
2005/0021107 A1	1/2005	Firlik et al.	2005/0283200 A1	12/2005	Rezai et al.
2005/0021118 A1	1/2005	Genau et al.	2005/0283201 A1	12/2005	Machado et al.
2005/0027284 A1	2/2005	Lozano et al.	2005/0283208 A1	12/2005	Von Arx et al.
2005/0028026 A1	2/2005	Shirley et al.	2005/0288600 A1	12/2005	Zhang et al.
2005/0033378 A1	2/2005	Sheffield et al.	2005/0288736 A1	12/2005	Persen et al.
2005/0033379 A1	2/2005	Lozano et al.	2005/0288760 A1	12/2005	Machado et al.
2005/0038326 A1	2/2005	Mathur	2006/0009815 A1	1/2006	Boveja et al.
2005/0038484 A1	2/2005	Knudson et al.	2006/0015153 A1	1/2006	Gliner et al.
2005/0049515 A1	3/2005	Misczynski et al.	2006/0020292 A1	1/2006	Goetz et al.
2005/0049655 A1	3/2005	Boveja et al.	2006/0020491 A1	1/2006	Mongeon et al.
2005/0060007 A1	3/2005	Goetz	2006/0041222 A1	2/2006	Dewing et al.
2005/0060008 A1	3/2005	Goetz	2006/0041223 A1	2/2006	Dewing et al.
2005/0060009 A1	3/2005	Goetz	2006/0041287 A1	2/2006	Dewing et al.
2005/0060010 A1	3/2005	Goetz	2006/0047205 A1	3/2006	Ludomirsky et al.
2005/0065553 A1 *	3/2005	Ben Ezra et al. 607/2	2006/0052843 A1	3/2006	Elsner et al.
2005/0065562 A1	3/2005	Rezai	2006/0058597 A1	3/2006	Machado et al.
2005/0065573 A1	3/2005	Rezai	2006/0064133 A1	3/2006	Von Arx et al.
2005/0065574 A1	3/2005	Rezai	2006/0064134 A1	3/2006	Mazar et al.
2005/0065575 A1	3/2005	Dobak	2006/0064143 A1	3/2006	Von Arx et al.
2005/0070971 A1	3/2005	Fowler et al.	2006/0069322 A1	3/2006	Zhang et al.
2005/0075679 A1	4/2005	Gliner et al.	2006/0074450 A1	4/2006	Boveja et al.
2005/0075680 A1	4/2005	Lowry et al.	2006/0079936 A1	4/2006	Boveja et al.
2005/0075681 A1	4/2005	Rezai et al.	2006/0079942 A1	4/2006	Deno et al.
2005/0075691 A1	4/2005	Phillips et al.	2006/0079945 A1	4/2006	Libbus
2005/0075701 A1	4/2005	Shafer	2006/0085046 A1	4/2006	Rezai et al.
2005/0075702 A1	4/2005	Shafer	2006/0094971 A1	5/2006	Drew
2005/0088145 A1	4/2005	Loch	2006/0095081 A1	5/2006	Zhou et al.
2005/0101873 A1	5/2005	Misczynski et al.	2006/0095090 A1	5/2006	De Ridder
2005/0102002 A1	5/2005	Salo et al.	2006/0100667 A1	5/2006	Machado et al.
2005/0107753 A1	5/2005	Rezai et al.	2006/0100668 A1	5/2006	Ben-David et al.
2005/0107842 A1	5/2005	Rezai	2006/0100671 A1	5/2006	Ridder
2005/0107858 A1	5/2005	Bluger	2006/0106430 A1	5/2006	Fowler et al.
2005/0113705 A1	5/2005	Fischell et al.	2006/0106431 A1	5/2006	Wylar et al.
2005/0113744 A1	5/2005	Donoghue et al.	2006/0111644 A1	5/2006	Gutttag et al.
2005/0119703 A1	6/2005	DiLorenzo	2006/0122525 A1	6/2006	Shusterman
2005/0124901 A1	6/2005	Misczynski et al.	2006/0122667 A1	6/2006	Chavan et al.
2005/0131467 A1	6/2005	Boveja	2006/0122864 A1	6/2006	Gottesman et al.
2005/0131485 A1	6/2005	Knudson et al.	2006/0135877 A1	6/2006	Giftakis et al.
2005/0131486 A1	6/2005	Boveja et al.	2006/0135881 A1	6/2006	Giftakis et al.
			2006/0155495 A1	7/2006	Osorio et al.
			2006/0161459 A9	7/2006	Rosenfeld et al.
			2006/0167497 A1	7/2006	Armstrong et al.
			2006/0173493 A1	8/2006	Armstrong et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2006/0173494 A1	8/2006	Armstrong et al.	2007/0239220 A1	10/2007	Greenhut et al.
2006/0173522 A1	8/2006	Osorio	2007/0244407 A1	10/2007	Osorio
2006/0190056 A1	8/2006	Fowler et al.	2007/0249953 A1	10/2007	Frei et al.
2006/0195155 A1	8/2006	Firlik et al.	2007/0249954 A1	10/2007	Virag et al.
2006/0195163 A1	8/2006	KenKnight et al.	2007/0250130 A1	10/2007	Ball et al.
2006/0200206 A1	9/2006	Firlik et al.	2007/0250145 A1	10/2007	Kraus et al.
2006/0200208 A1	9/2006	Terry et al.	2007/0255147 A1	11/2007	Drew et al.
2006/0212091 A1	9/2006	Lozano et al.	2007/0255155 A1	11/2007	Drew et al.
2006/0217780 A1	9/2006	Gliner et al.	2007/0255330 A1	11/2007	Lee et al.
2006/0220839 A1	10/2006	Fifolt et al.	2007/0255337 A1	11/2007	Lu
2006/0224067 A1	10/2006	Giftakis et al.	2007/0255374 A1	11/2007	Kolafa et al.
2006/0224188 A1	10/2006	Libbus et al.	2007/0260147 A1	11/2007	Giftakis et al.
2006/0224191 A1	10/2006	Dilorenzo	2007/0260289 A1	11/2007	Giftakis et al.
2006/0241697 A1	10/2006	Libbus et al.	2007/0265489 A1	11/2007	Fowler et al.
2006/0241725 A1	10/2006	Libbus et al.	2007/0265508 A1	11/2007	Sheikhzadeh-Nadjar et al.
2006/0247719 A1	11/2006	Maschino et al.	2007/0265536 A1	11/2007	Giftakis et al.
2006/0247722 A1	11/2006	Maschino et al.	2007/0272260 A1	11/2007	Nikitin et al.
2006/0253164 A1	11/2006	Zhang et al.	2007/0282177 A1	12/2007	Pilz
2006/0253168 A1	11/2006	Wyler et al.	2007/0287931 A1	12/2007	Dilorenzo
2006/0253169 A1	11/2006	Wyler et al.	2007/0288072 A1	12/2007	Pascual-Leone et al.
2006/0253170 A1	11/2006	Wyler et al.	2007/0299349 A1	12/2007	Alt et al.
2006/0253171 A1	11/2006	Wyler et al.	2007/0299473 A1	12/2007	Matos
2006/0259095 A1	11/2006	Wyler et al.	2007/0299480 A1	12/2007	Hill
2006/0264730 A1	11/2006	Stivoric et al.	2008/0015651 A1	1/2008	Ettori et al.
2006/0265018 A1	11/2006	Smith et al.	2008/0015652 A1	1/2008	Maile et al.
2006/0271108 A1	11/2006	Libbus et al.	2008/0021332 A1	1/2008	Brainard
2006/0271409 A1	11/2006	Rosenfeld et al.	2008/0021341 A1	1/2008	Harris et al.
2006/0293720 A1	12/2006	DiLorenzo	2008/0021517 A1	1/2008	Dietrich
2006/0293721 A1	12/2006	Tarver et al.	2008/0021520 A1	1/2008	Dietrich
2007/0021786 A1	1/2007	Parnis et al.	2008/0027347 A1	1/2008	Harris et al.
2007/0027486 A1	2/2007	Armstrong	2008/0027348 A1	1/2008	Harris et al.
2007/0032734 A1	2/2007	Najafi et al.	2008/0027515 A1	1/2008	Harris et al.
2007/0032834 A1	2/2007	Gliner et al.	2008/0033502 A1	2/2008	Harris et al.
2007/0038262 A1	2/2007	Kieval et al.	2008/0033503 A1	2/2008	Fowler et al.
2007/0043392 A1	2/2007	Gliner et al.	2008/0033508 A1	2/2008	Frei et al.
2007/0055320 A1	3/2007	Weinand	2008/0046035 A1	2/2008	Fowler et al.
2007/0073150 A1	3/2007	Gopalsami et al.	2008/0046037 A1	2/2008	Haubrich et al.
2007/0073346 A1	3/2007	Corbucci	2008/0046038 A1	2/2008	Hill et al.
2007/0073355 A1	3/2007	Dilorenzo	2008/0051852 A1	2/2008	Dietrich et al.
2007/0078491 A1	4/2007	Siejko et al.	2008/0058884 A1	3/2008	Matos
2007/0088403 A1	4/2007	Wyler et al.	2008/0064934 A1	3/2008	Frei et al.
2007/0088404 A1	4/2007	Wyler et al.	2008/0071323 A1	3/2008	Lowry et al.
2007/0088405 A1	4/2007	Jacobson	2008/0077028 A1	3/2008	Schaldach et al.
2007/0100278 A1	5/2007	Frei et al.	2008/0103548 A1	5/2008	Fowler et al.
2007/0100397 A1	5/2007	Seeberger et al.	2008/0114417 A1	5/2008	Leyde
2007/0100398 A1	5/2007	Sloan	2008/0119900 A1	5/2008	DiLorenzo
2007/0112393 A1	5/2007	Gliner	2008/0125820 A1	5/2008	Stahmann et al.
2007/0123946 A1	5/2007	Masoud	2008/0139870 A1	6/2008	Gliner et al.
2007/0135855 A1	6/2007	Foshee et al.	2008/0146890 A1	6/2008	LeBoeuf et al.
2007/0142862 A1	6/2007	Dilorenzo	2008/0146959 A1	6/2008	Sheffield et al.
2007/0142873 A1	6/2007	Esteller et al.	2008/0161712 A1	7/2008	Leyde
2007/0149952 A1	6/2007	Bland et al.	2008/0161713 A1	7/2008	Leyde et al.
2007/0150011 A1	6/2007	Meyer et al.	2008/0161879 A1	7/2008	Firlik et al.
2007/0150014 A1	6/2007	Kramer et al.	2008/0161880 A1	7/2008	Firlik et al.
2007/0150024 A1	6/2007	Leyde et al.	2008/0161881 A1	7/2008	Firlik et al.
2007/0150025 A1	6/2007	Dilorenzo et al.	2008/0161882 A1	7/2008	Firlik et al.
2007/0156179 A1	7/2007	S.E.	2008/0183096 A1	7/2008	Snyder et al.
2007/0156450 A1	7/2007	Roehm et al.	2008/0183097 A1	7/2008	Leyde et al.
2007/0156626 A1	7/2007	Roehm et al.	2008/0183245 A1	7/2008	Van Oort et al.
2007/0161919 A1	7/2007	DiLorenzo	2008/0195175 A1	8/2008	Balzer et al.
2007/0162086 A1	7/2007	DiLorenzo	2008/0200925 A1	8/2008	Johnson et al.
2007/0167991 A1	7/2007	DiLorenzo	2008/0208013 A1	8/2008	Zhang et al.
2007/0173901 A1	7/2007	Reeve	2008/0208074 A1	8/2008	Snyder et al.
2007/0179534 A1	8/2007	Firlik et al.	2008/0208285 A1	8/2008	Fowler et al.
2007/0179558 A1	8/2007	Gliner et al.	2008/0208291 A1	8/2008	Leyde et al.
2007/0179584 A1	8/2007	Gliner	2008/0208781 A1	8/2008	Snyder
2007/0203548 A1	8/2007	Pawelzik et al.	2008/0215112 A1	9/2008	Firlik et al.
2007/0208212 A1	9/2007	DiLorenzo	2008/0215114 A1	9/2008	Stuerzinger et al.
2007/0208390 A1	9/2007	Von Arx et al.	2008/0221644 A1	9/2008	Vallapureddy et al.
2007/0213785 A1	9/2007	Osorio et al.	2008/0234598 A1	9/2008	Snyder et al.
2007/0233192 A1	10/2007	Craig	2008/0249591 A1	10/2008	Gaw et al.
2007/0233193 A1	10/2007	Craig	2008/0255582 A1	10/2008	Harris
2007/0238939 A1	10/2007	Giftakis et al.	2009/0054795 A1	2/2009	Misczynski et al.
2007/0239210 A1	10/2007	Libbus et al.	2009/0076567 A1	3/2009	Fowler et al.
2007/0239211 A1	10/2007	Lorincz et al.			

(56)

References Cited

U.S. PATENT DOCUMENTS

2009/0171405 A1 7/2009 Craig
 2009/0177252 A1 7/2009 Craig
 2012/0191158 A1 7/2012 Craig

FOREIGN PATENT DOCUMENTS

CA 2339971 A1 2/2000
 CA 2653110 A1 10/2007
 CA 2653112 A1 10/2007
 EP 0402683 A2 12/1990
 EP 0713714 A2 5/1996
 EP 1070518 A2 1/2001
 EP 1120130 A2 8/2001
 EP 1139861 A1 10/2001
 EP 1145736 A2 10/2001
 EP 1202775 A1 5/2002
 EP 1304135 A2 4/2003
 EP 1486232 A2 12/2004
 EP 1595497 A1 11/2005
 EP 1634617 A1 3/2006
 EP 1647300 A2 4/2006
 EP 1745818 A1 1/2007
 GB 2026870 A 2/1980
 GB 2079610 A 1/1982
 JP 11-514268 12/1999
 JP 2001-505441 A 4/2001
 JP 2003-180847 A 7/2003
 JP 2004-524125 A 8/2004
 JP 2009/503279 A 1/2009
 JP 2009/503285 A 1/2009
 JP 2011-514268 A 5/2011
 WO WO-93/01862 A1 2/1993
 WO WO-93/02744 A1 2/1993
 WO WO-93/21824 A1 11/1993
 WO WO-94/00185 A1 1/1994
 WO WO-94/00188 A1 1/1994
 WO WO-94/17771 A2 8/1994
 WO WO-98/25688 A1 6/1998
 WO WO-99/56822 A1 11/1999
 WO WO-00/40143 A1 7/2000
 WO WO-00/64336 A1 11/2000
 WO WO-01/05467 A1 1/2001
 WO WO-01/08749 A1 2/2001
 WO WO-03/076010 A1 9/2003
 WO WO-03/085546 A1 10/2003
 WO WO-2004/036377 A2 4/2004
 WO WO-2004/064918 A1 8/2004
 WO WO-2004/069330 A1 8/2004
 WO WO-2004/071575 A1 8/2004
 WO WO-2004/075982 A1 9/2004
 WO WO-2004/112894 A1 12/2004
 WO WO-2005/007120 A2 1/2005
 WO WO-2005/007232 A2 1/2005
 WO WO-2005/028026 A1 3/2005
 WO WO-2005/053788 A1 6/2005
 WO WO-2005/067599 A2 7/2005
 WO WO-2005/101282 A2 10/2005
 WO WO-2006/014760 A1 2/2006
 WO WO-2006/019764 A2 2/2006
 WO WO-2006/019822 A2 2/2006
 WO WO-2006/050144 A1 5/2006
 WO WO-2006/118793 A2 11/2006
 WO WO-2006/122148 A2 11/2006
 WO WO-2007/066343 A2 6/2007
 WO WO-2007/072425 A2 6/2007
 WO WO-2007/115103 A1 10/2007
 WO WO-2007/115113 A1 10/2007
 WO WO-2007/115118 A1 10/2007
 WO WO-2007/124126 A2 11/2007
 WO WO-2007/124190 A2 11/2007
 WO WO-2007/124192 A1 11/2007
 WO WO-2007/142523 A1 12/2007

OTHER PUBLICATIONS

Bohning, et al., "Feasibility of Vagal Nerve Stimulation—Synchronized Blood Oxygenation Level-Dependent Functional MRI," *A Journal of Clinical and Laboratory Research: Investigative Radiology*, vol. 36, No. 8 (Aug. 2001) (pp. 470-479).
 Boon, et al., "Programmed and Magnet-Induced Vagus Nerve Stimulation for Refractory Epilepsy," *Journal of Clinical Neurophysiology*, vol. 18, No. 5 (2001) (pp. 402-407).
 Clark, et al., "Enhanced Recognition Memory Following Vagus Nerve Stimulation in Human Subjects," *Nature Neuroscience*, vol. 2, No. 1 (Jan. 1999) (pp. 93-98).
 Clark, et al., "Posttraining Electrical Stimulation of Vagal Afferents with Concomitant Vagal Efferent Inactivation Enhances Memory Storage Process in the Rat," *Neurobiology of Learning and Memory*, vol. 70 (1998) Art No. NL983863 (pp. 364-373).
 Craig, A.D. "Mechanisms of thalamic pain; central neuropathic pain; focus on poststroke pain." IASP Press, Seattle, Washington (2007).
 Craig, A.D. "Vagal input to lateral area 3a in cat cortex." *J. Neurophysiol.* 90, pp. 143-154 (Jan. 15, 2003).
 Craig, A.D. (BUD), "Distribution of Trigeminothalamic and Spinothalamic Lamina I Terminations in the Macaque Monkey," *The Journal of Comparative Neurology*, vol. 477 (2004) (pp. 119-148).
 DeGiorgio, et al., "Vagus Nerve Stimulation: Analysis of Device Parameters in 154 Patients During the Long-Term XE5 Study," *Epilepsia*, vol. 42, No. 8 (2001) (pp. 1017-1020).
 DeVous, et al., "Effects of Vagus Nerve Stimulation on Regional Cerebral Blood Flow in Treatment-Resistant Depression," *National Institute of Mental Health—42nd Annual NCDEU Meeting: Poster Session II; Poster Abstracts*, Jun. 10-13, 2002, 1 page.
 Dodrill, et al., "Effects of Vagal Nerve Stimulation on Cognition and Quality of Life in Epilepsy," *Epilepsy and Behavior*, vol. 2 (2001) (pp. 46-53).
 Fanselow, et al., "Reduction of Pentylentetrazole-Induced Seizure Activity in Awake Rats by Seizure-Triggered Trigeminal Nerve Stimulation," *The Journal of Neuroscience*, vol. 20, No. 21 (Nov. 2001) (p. 8160-8168).
 Fromes, et al., "Clinical Utility of On-Demand Magnet use with Vagus Nerve Stimulation," *AES Proceedings* (pp. 117).
 George, et al., "Open Trial of VNS Therapy in Severe Anxiety Disorders," *156th American Psychiatric Association Annual Meeting*; May 12-23, 2003.
 George, et al., "Vagus Nerve Stimulation: A New Tool for Brain Research and Therapy," *Society of Biological Psychiatry*, vol. 47 (2000) (pp. 287-295).
 Hallowitz, et al., "Effects of Vagal Trolleys on Units of Intralaminar and Juxtalamina Thalamic Nuclei in Monkeys," *Brain Research*, vol. 130 (1977) (pp. 271-286).
 Harry, et al., "Balancing Act: Noise is the Key to Restoring the Body's Sense of Equilibrium," *IEEE Spectrum* (Apr. 2005) (pp. 37-41).
 Henry, et al., "Brain Blood-Flow Alteration Induced by Therapeutic Vagus Nerve Stimulation in Partial Epilepsy: I. Acute Effects at High and Low Levels of Stimulation," *Epilepsia*, vol. 29, No. 9 (1998) (pp. 984-990).
 Henry, T.R., "Therapeutic Mechanisms of Vagus Nerve Stimulation," *Neurology*, vol. 59, Suppl. 4 (Sep. 2002) (pp. S3-S14).
 Ito, et al., "Forebrain Projections of the Vagal Responsive Site in the Thalamic Parafascicular Nucleus in Monkey," *Presentation 305.2*, Nov. 13, 2005, Washington D.C.
 Ito, et al., "Vagal-Evoked Activity in the Parafascicular Nucleus of the Primate Thalamus," *J. Neurophysiol.* 94, May 31, 2005 (pp. 2976-2982).
 King, M.D., "Effects of Short-Term Vagus Nerve Stimulation (VNS) on FOS Expression in Rat Brain Nuclei," *58th Annual Scientific Convention of the Society of Biological Psychiatry*, (May 2003).
 Klabunde, R.E. "Electrocardiogram (EKG, ECG)." *Cardiovascular Physiology Concepts*. <http://www.cvphysiology.com/Arrhythmias/A009.htm>. Revised Apr. 6, 2007.
 Klapper, et al., "VNS Therapy Shows Potential Benefit in Patients with Migraine an Chronic Daily Headache Afte 3 to 6 Months of

(56)

References Cited**OTHER PUBLICATIONS**

Treatment (Preliminary Results)," 45th Annual Scientific Meeting of the American Headache Society (Jun. 2003).

Koo, B., "EEG Changes With Vagus Nerve Stimulation," *Journal of Clinical Neurophysiology*, vol. 18, No. 5 (Sep. 2001) (pp. 434-441).

Labar, D., "Vagus Nerve Stimulation for 1 Year in 269 Patients on Unchanged Antiepileptic Drugs," *Seizure*, vol. 13 (2004) (pp. 392-398).

Liebman, et al., "Improvement in Cognitive Function After Vagal Nerve Stimulator Implantation," *Epilepsia*, vol. 39, Suppl. 6 (1998) (1page).

Lockard, et al., "Feasibility and Safety of Vagal Stimulation in Monkey Model," *Epilepsia*, vol. 31, Suppl. 2 (1990) (pp. S20-S26).

Malow, et al., "Vagus Nerve Stimulation Reduces Daytime Sleepiness in Epilepsy Patients," *Neurology* 57 (2001) (pp. 879-884).

McClintock, P., "Can Noise Actually Boost Brain Power," *Physics World* Jul. 2002 (pp. 20-21).

Mori, et al., "Noise-Induced Entrainment and Stochastic Resonance in Human Brain Waves," *Physical Review Letters* vol. 88, No. 21 (2002) (pp. 218101-1-218101-4).

Rugg-Gunn, et al., "Cardiac Arrhythmias in Focal Epilepsy: a Prospective Long-Term Study," *www.thelancet.com*, vol. 364 (2004) (pp. 2212-2219).

Rutecki, P., "Anatomical Physiological, and Theroetical Basis for the Antiepileptic Effect of Vagus Nerve Stimulation," *Epilepsia*, vol. 31, Suppl. 2, (1990) (pp. S1-S6).

Sahin, et al., "Improved Nerve Cuff Electrode Recording with Sub-threshold Anodic Currents," *IEEE Transactions on Biomedical Engineering*, vol. 45, No. 8 (ug 1998) (pp. 1044-1050).

Schachter, et al., "Progress in Epilepsy Research: Vagus Nerve Stimulation," *Epilepsia*, vol. 39, No. 7 (1998) (pp. 677-686).

Tatum, et al., "Vagus Nerve Stimulation and Drug Reduction," *Neurology*, vol. 56, No. 4 (Feb. 2001) (pp. 561-563).

Tatum, et al., "Ventricular Asystole During Vagus Nerve Stimulation for Epilepsy in Humans," *Amerian Academy of Neurology* (1999) (pp. 1267 See also pp. 1117, 1166, and 1265).

Terry, et al., "The Implantable Neurocybernetic Prosthesis System," *Pacing and Clinical Electrophysiology*, vol. 14, No. 1 (Jan. 1991) (pp. 86-93).

Tubbs, et al., "Left Sided Vagus Nerve Stimulation Decreases Intracranial Pressure Without Resultant Bradycardia in the Pig: A Potential Therapeutic Modality for Humans" *Child's Nervous System Original Paper*; Springer-Verlag (2004).

Valdez-Cruz, et al., "Chronic Stimulation of the Cat Vagus Nerve Effect on Sleep and Behavior," *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, vol. 26 (2002) (pp. 113-118).

Vonck, et al., "The Mechanism of Action of Vagus Nerve Stimulaiton for Refractory Epilepsy—The current Status," *Journal of Neurophysiology*, vol. 18, No. 5 (2001) (pp. 394-401).

Ward, et al., "Treatment-Refractory Obsessive-Compulsive Disorder: Potential Benefit of VNS Therapy," 23rd Annual Conference of the Anxiety Disorders Association of America (2007).

Woodbury, et al., "Vagal Stimulation Reduces the Severity of Maximal Electroshock Seizures in Intact Rats. Use of a Cuff Electrode for Stimulation and Recording," *Pacing and Clinical Electrophysiology*, vol. 14 (Jan. 1991) (pp. 1005-1012).

Zabara, J., "Inhibition of Experimental Seizures in Canines by Repetitive Vagal Stimulation," *Epilepsia*, vol. 33, No. 6 (1992) (pp. 1005-1012).

International Preliminary Report on Patentability issued Sep. 30, 2008 by the International Searching Authority for Application PCT/US2007/065537, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-7).

International Search Report issued Aug. 31, 2007 by the International Searching Authority for Application PCT/US2007/065537, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-5).

Written Opinion issued Aug. 31, 2007 by the International Searching Authority for Application PCT/US2007/065537, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-6).

Amendment and Response to Final Office Action filed Oct. 10, 2011 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Amendment and Response to Non-Final Office Action filed Feb. 11, 2011 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Amendment and Response to Restriction Requirement filed Jun. 18, 2010 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Final Office Action issued Apr. 8, 2011 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Issue Notification issued Mar. 14, 2012 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Non-Final Office Action issued Aug. 12, 2010 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Notice of Allowance issued Dec. 13, 2011 for U.S. Appl. No. 11/693,421, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Restriction Requirement issued Mar. 18, 2010 for U.S. Appl. No. 11/693,421, filed which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Dignity Health) (pp. 1-11).

Amendment and Response to Final Office Action filed Apr. 5, 2012 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-20).

Amendment and Response to Non-Final Office Action filed Aug. 23, 2011 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Amendment and Response to Non-Final Office Action filed Jun. 17, 2010 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-13).

Amendment in Response to Final Office Action filed Feb. 8, 2011 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-12).

Examiner Interview Summary Record issued May 12, 2010 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Final Office Action issued Aug. 10, 2010 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Final Office Action issued Nov. 18, 2011 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Issue Notification issued Sep. 12, 2012 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Non-Final Office Action issued Feb. 15, 2011 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Non-Final Office Action issued Mar. 17, 2010 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Notice of Allowance issued Jun. 8, 2012 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Request for Continued Examination filed Feb. 8, 2011 for U.S. Appl. No. 12/400,893, filed on Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Supplemental Non-Final Office Action issued Feb. 23, 2011 for U.S. Appl. No. 12/400,893, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

International Preliminary Report on Patentability issued Sep. 30, 2008 for PCT/US2007/065531, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-7).

International Search Report and Written Opinion issued Sep. 14, 2007 for PCT/US2007/065531, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

(56)

References Cited**OTHER PUBLICATIONS**

Advisory Action issued Jun. 15, 2011 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Amendment After Non-Final Office Action filed Aug. 16, 2010 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Amendment and Response to Non-Final Office Action filed Mar. 14, 2012 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-15).

Amendment and Response to Supplemental Final Office Action filed May 27, 2011 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Examiner Interview Summary Record issued May 11, 2010 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Final Office Action issued Sep. 28, 2010 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-15).

Issue Notification issued Jun. 20, 2012 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Non-Final Office Action issued Mar. 16, 2010 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Non-Final Office Action issued Oct. 14, 2011 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Notice of Allowance issued Apr. 3, 2012 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-4).

Response to Final Office Action filed Sep. 1, 2011 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Supplemental Final Office Action issued Mar. 1, 2011 for U.S. Appl. No. 11/693,499, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-14).

Amendment and Response to Final Office Action filed May 9, 2011 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-22).

Amendment and Response to Non-Final Office Action filed Aug. 19, 2010 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-24).

Final Office Action issued on Nov. 15, 2010 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-17).

Non-Final Office Action issued Apr. 19, 2010 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Non-Final Office Action issued Jun. 19, 2013 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-13).

International Preliminary Report on Patentability issued Sep. 30, 2008 by the International Searching Authority for Application PCT/US2007/065518, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-7).

International Search Report issued Aug. 30, 2007 by the International Searching Authority for Application PCT/US2007/065518, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-4).

Written Opinion issued Aug. 30, 2007 by the International Searching Authority for Application PCT/US2007/065518, which was filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Catholic Healthcare West) (pp. 1-6).

Amendment and Response filed Aug. 23, 2010 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-20).

Amendment and Response to Non-Final Office Action filed on Jan. 25, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-13).

Amendment in Response to Final Office Action filed Jul. 26, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-7).

Applicant Argument/Remarks made in an Amendment for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-12).

Applicant-Initiated Interview Summary issued Feb. 22, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Examiner's Search Strategy and Results issued Oct. 22, 2010 by the United States Patent and Trademark Office for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Final Office Action issued May 16, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-11).

Final Office Action issued on Oct. 22, 2010 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-15).

First Office Action issued Apr. 21, 2010 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-17).

Non-Final Office Action issued Jul. 27, 2012 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-23).

Notice of Allowance issued Aug. 19, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-6).

Notice of References Cited issued Apr. 21, 2010 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Supplemental Amendment in Response to Non-Final Office Action filed Mar. 21, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Supplemental Amendment to Final Office Action filed Aug. 9, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Amendment and Response filed Jan. 16, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-13).

Amendment and Response to Office Action for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-21).

Amendment in Response to Office Action filed Jun. 14, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

Applicant Initiated Interview Summary issued Feb. 25, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Examiners Search Strategy and Results issued Dec. 2, 2011 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Final Office Action issued Jul. 16, 2012 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-18).

Non-Final Office Action issued Mar. 28, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-12).

Non-Final Office Action issued Dec. 2, 2011 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-15).

Supplemental Amendment in Response to Final Office Action filed Mar. 21, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-10).

Request for Continued Examination filed May 9, 2011 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Response to Non-Final Office Action filed Sep. 19, 2013 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-17).

Notice of Allowance issued Jan. 13, 2014 for U.S. Appl. No. 12/401,026, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-8).

(56)

References Cited

OTHER PUBLICATIONS

Issue Notification issued Dec. 4, 2013 for U.S. Appl. No. 11/693,451, filed Mar. 29, 2007 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Request for Continued Examination filed Jan. 16, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-3).

Examiner Initiated Interview Summary issued Oct. 10, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Notice of Allowance issued Oct. 10, 2013 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-9).

Issue Notification issued Feb. 5, 2014 for U.S. Appl. No. 12/400,970, filed Mar. 10, 2009 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-1).

Preliminary Amendment filed Nov. 25, 2013 for U.S. Appl. No. 14/089,185, filed Nov. 25, 2013 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-6).

Preliminary Amendment filed Feb. 18, 2014 for U.S. Appl. No. 14/089,185, filed Nov. 25, 2013 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-44).

Preliminary Amendment filed Jan. 10, 2014 for U.S. Appl. No. 14/152,428, filed Jan. 10, 2014 (Inventor—Arthur D. Craig; Applicant—Dignity Health) (pp. 1-5).

* cited by examiner

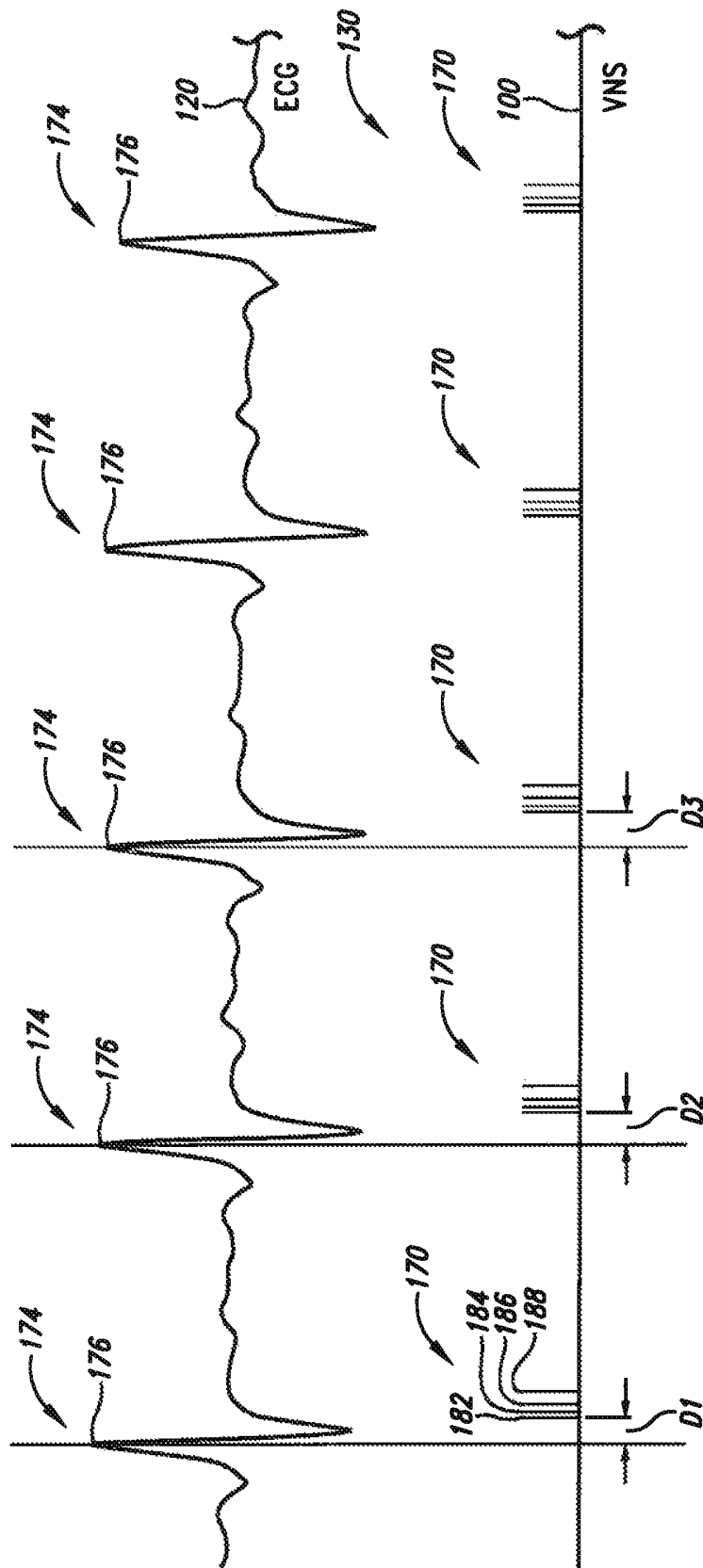
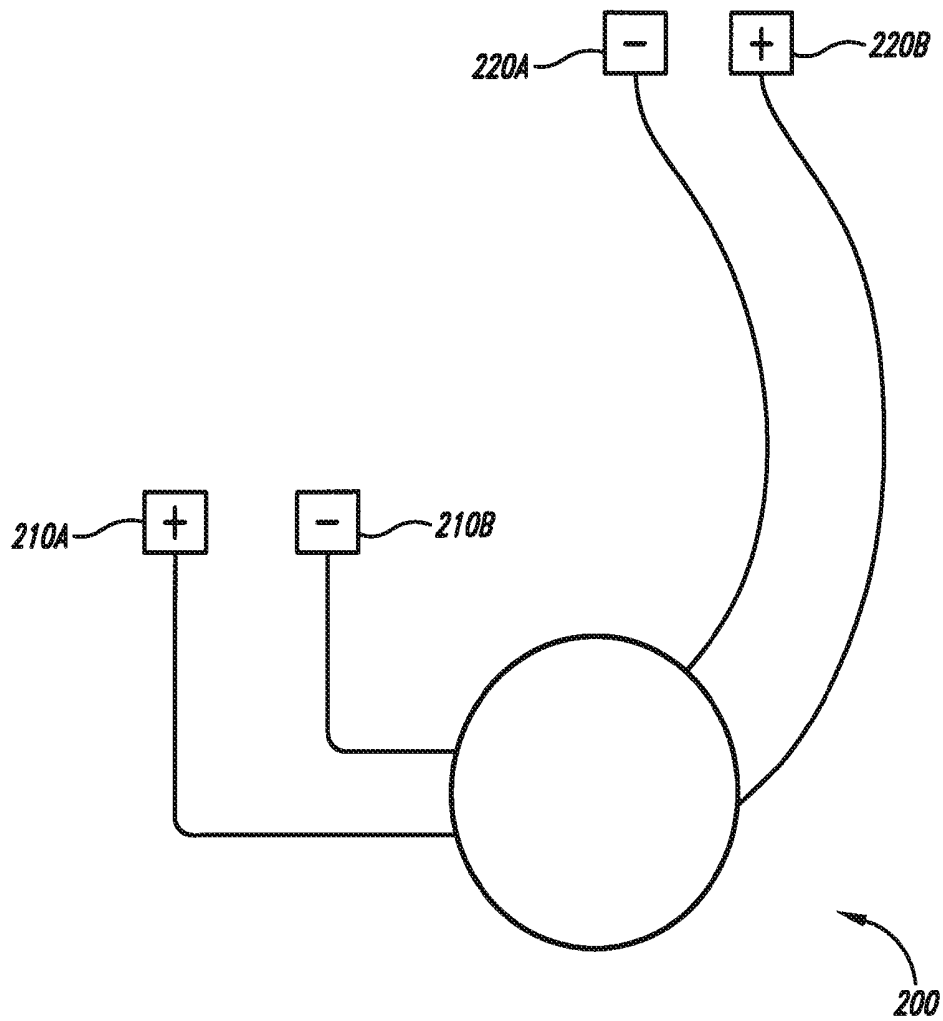
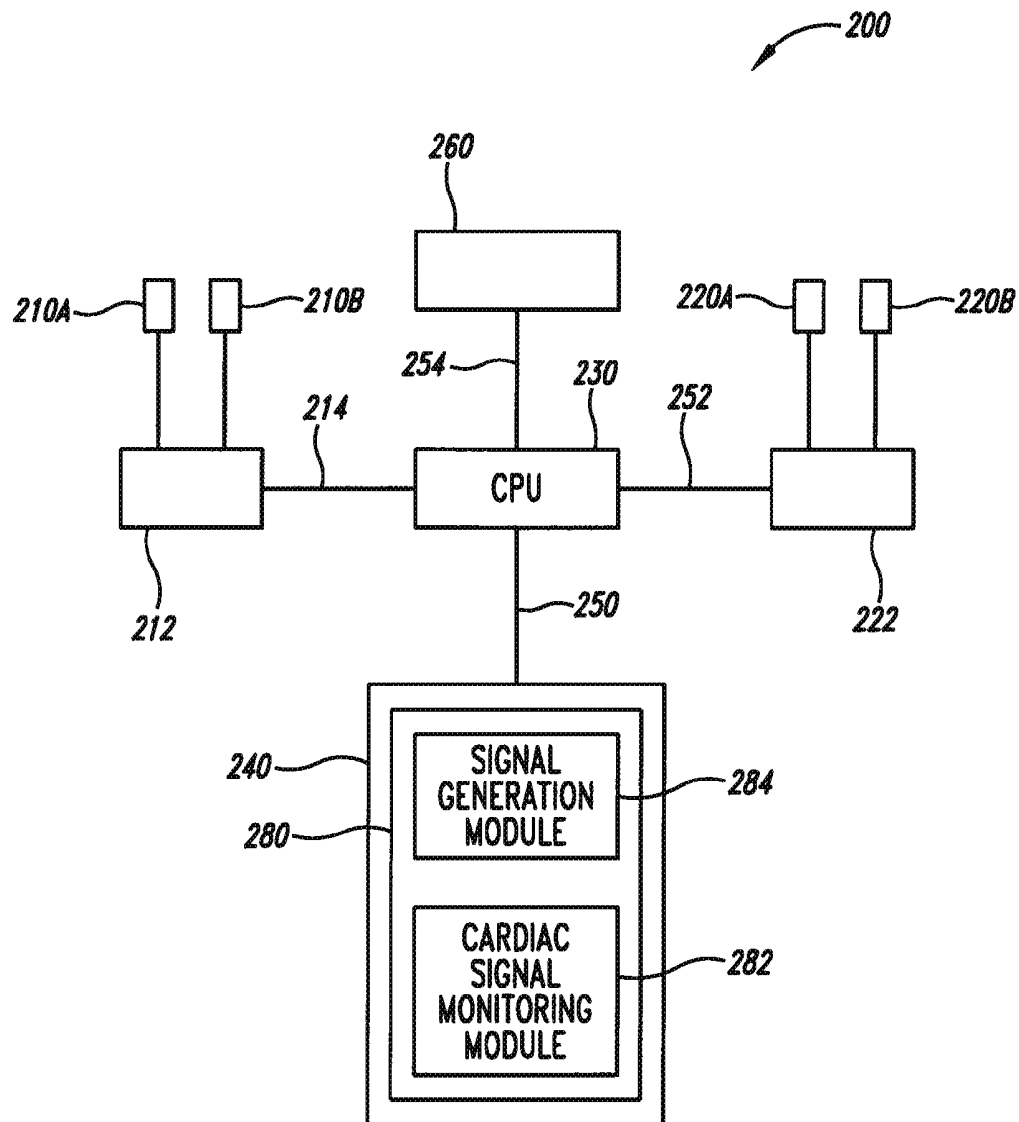
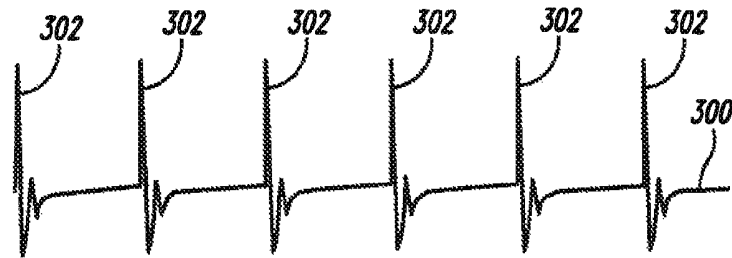
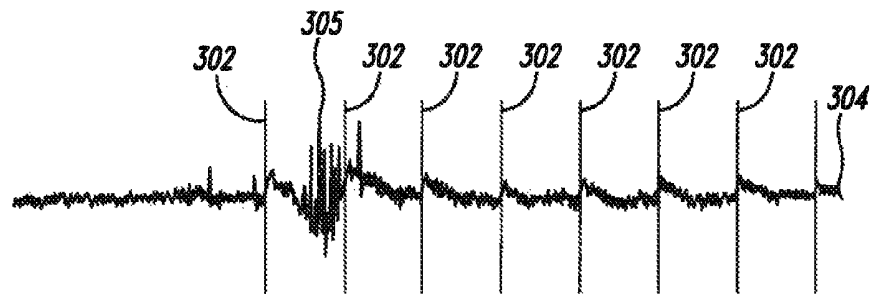
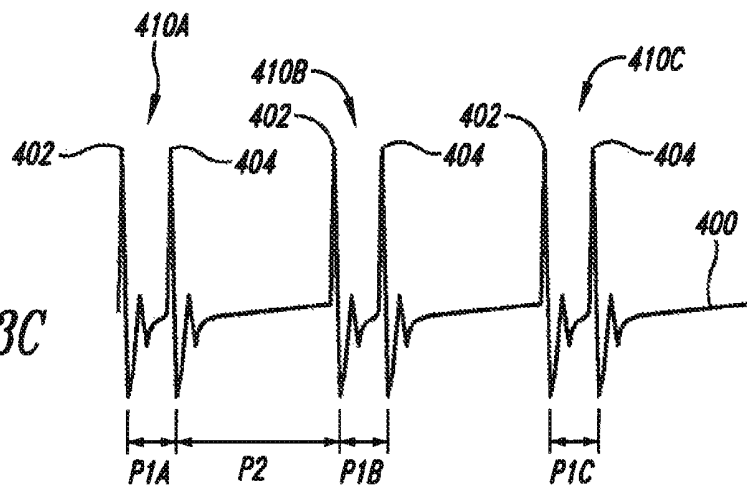
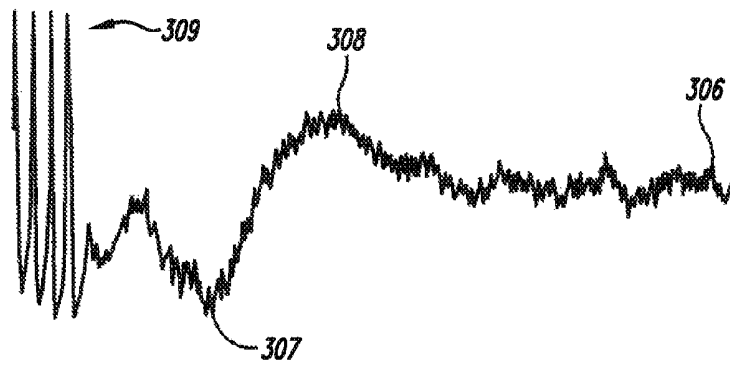
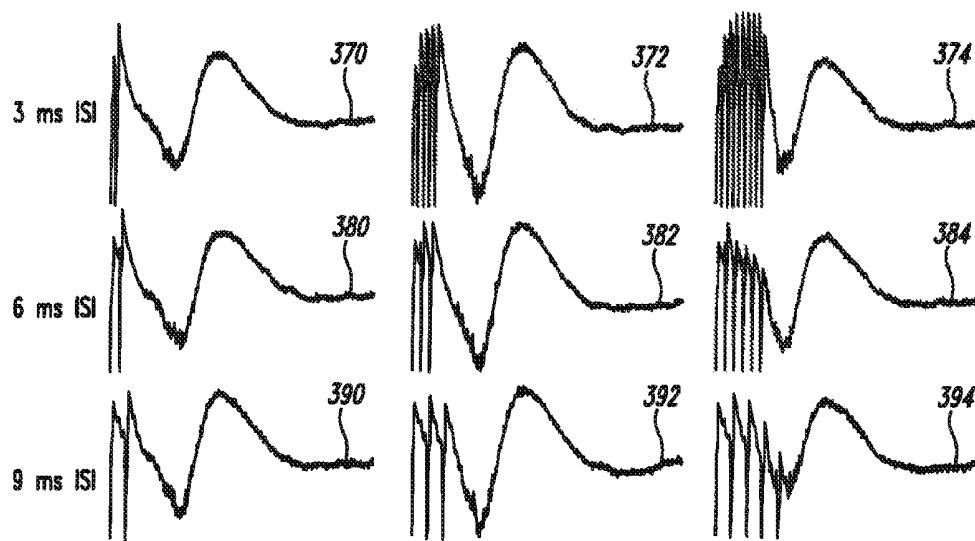


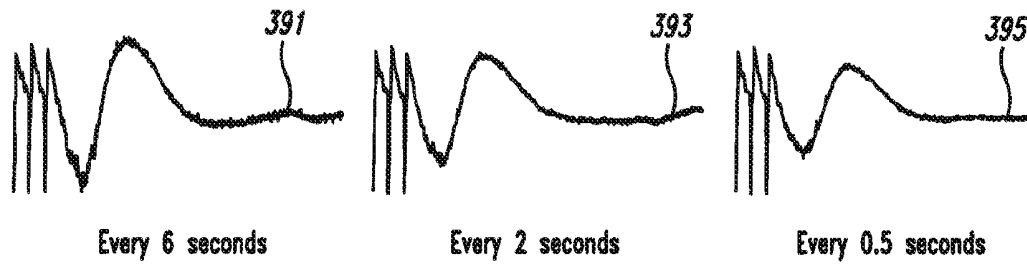
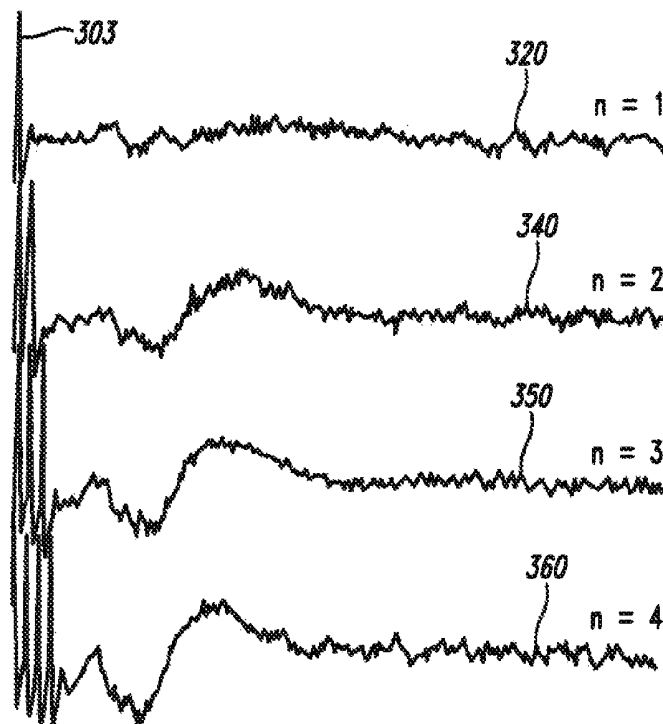
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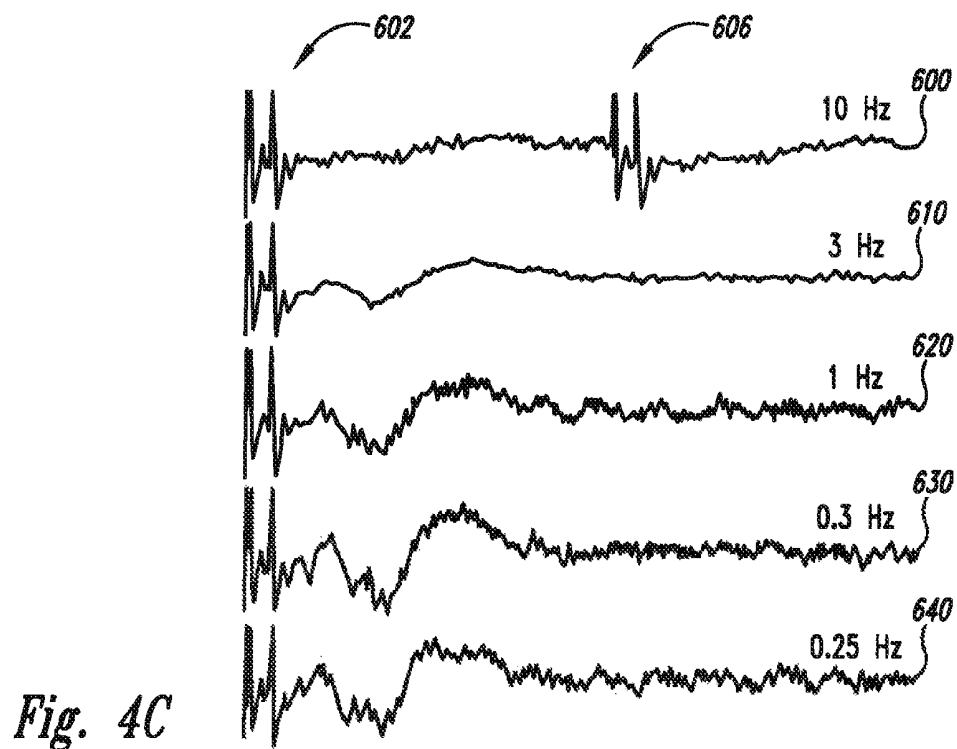
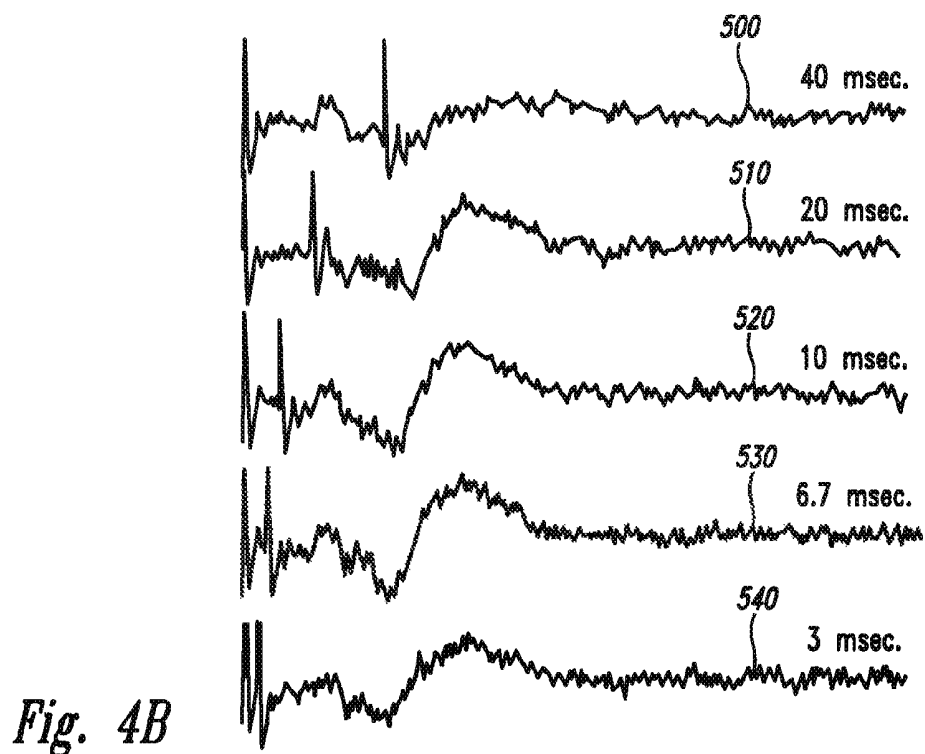
*Fig. 2A*

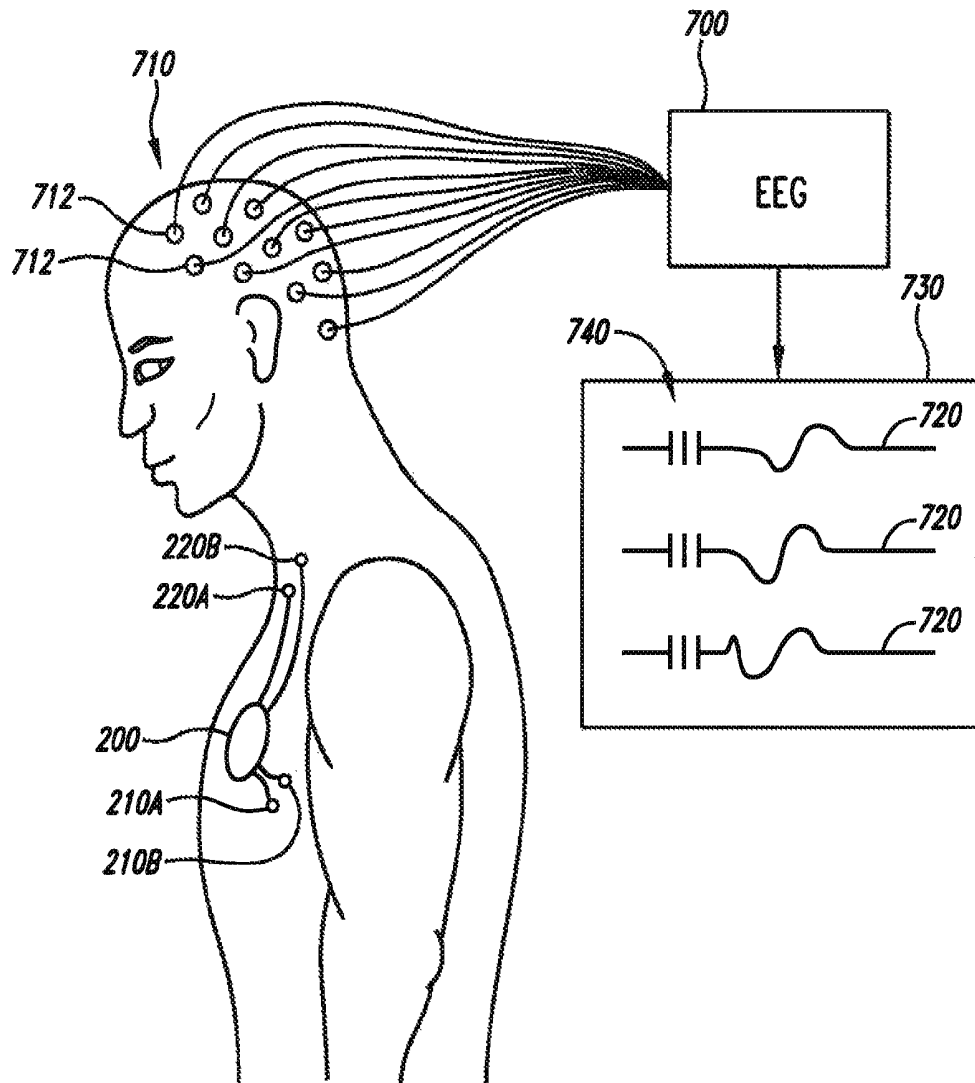
*Fig. 2B*

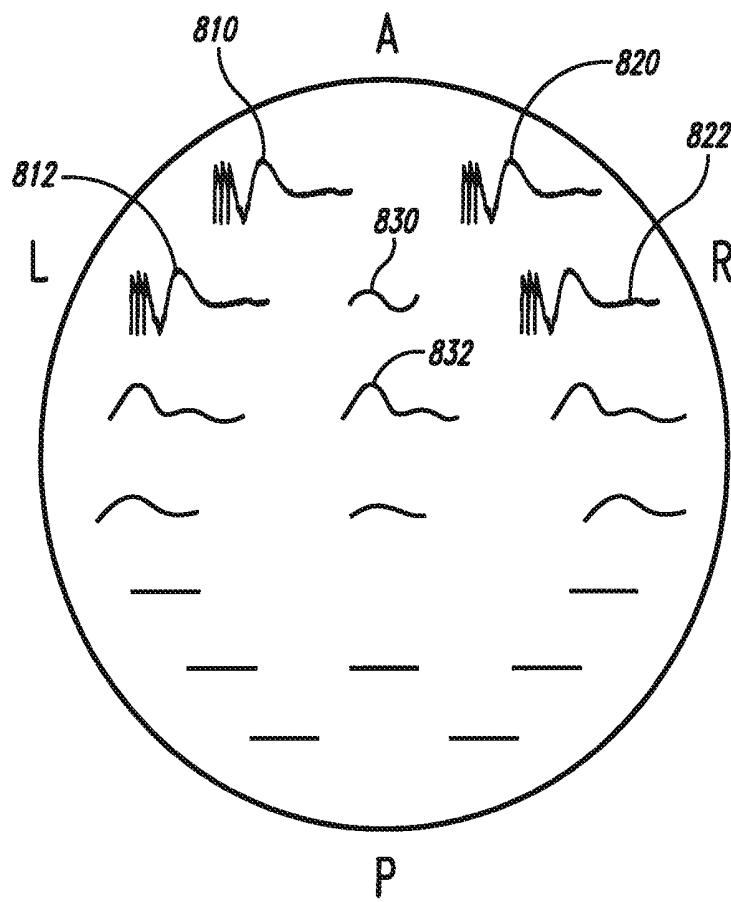
*Fig. 3A**Fig. 3B**Fig. 3C*

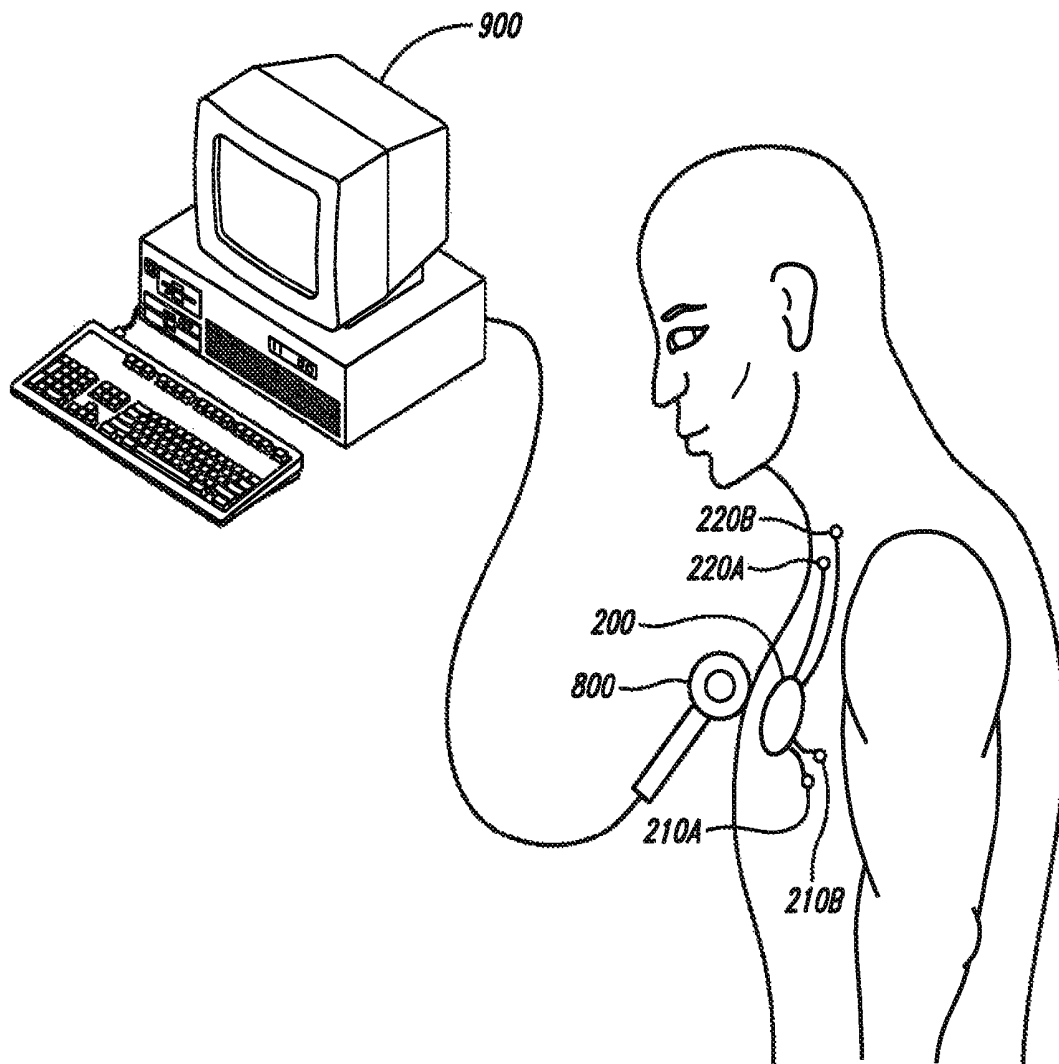
*Fig. 3D**Fig. 3E*

*Fig. 3F**Fig. 4A*



*Fig. 5*

*Fig. 6*

*Fig. 7*

VAGUS NERVE STIMULATION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and claims priority to U.S. patent application Ser. No. 11/693,421, filed Mar. 29, 2007, entitled "Vagus Nerve Stimulation Method," which granted as U.S. Pat. No. 8,150,508 on Apr. 3, 2012, and the benefit of U.S. Provisional Patent Application Serial No. 60/787,680, filed Mar. 29, 2006, entitled "Vagus Nerve Stimulation Method" is hereby claimed, and the specifications thereof are incorporated herein in their entireties by this reference.

The United States patent application entitled "Microburst Electrical Stimulation Of Cranial Nerves For The Treatment Of Medical Conditions," by Arthur D. Craig and filed concurrently herewith is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed generally to neurostimulation of the vagus nerve, and more particularly to an improved apparatus and method for vagus nerve stimulation therapy using heart rate variability synchronization, patterned electrical pulses inside a pulse burst, and electroencephalogram ("EEG") based optimization.

2. Description of the Related Art

Vagus nerve stimulation ("VNS") (for example, VNS Therapy™ by Cyberonics, Inc.) is an FDA-approved method for alleviating treatment-resistant epilepsy and depression.

Vagus nerve stimulation was initially developed and approved by the FDA for the treatment of refractory partial onset epilepsy. Recently, it has been reported that the use of VNS in human patients with epilepsy is associated with an improvement in mood. As a consequence, VNS has also been approved as a treatment for refractory depression (treatment resistant depression).

VNS typically involves implanting a nerve stimulating electrode on the left or right vagus nerve in the neck. The electrode is connected to a subcutaneous pacemaker-like control unit that generates an electrical nerve stimulating signal. A Vagus Nerve Stimulator ("VNS stimulator") is an example of an implantable stopwatch-sized, pacemaker-like control unit device configured to electrically stimulate the vagus nerve leading to the brain.

Conventional VNS is generally applied every 5 minutes in a 7 second to one minute burst (see FIG. 3A for a portion of an exemplary burst) including a pulse train of uniformly spaced apart pulses having a pulse current amplitude of about 0.5 mA to about 2.0 mA). The pulses are delivered at about 20 Hz to about 50 Hz. Each of the pulses may have a width of about 0.5 milliseconds. VNS is currently approved to treat epileptic seizures and depression when drugs have been ineffective.

Consequently, a need exists for methods of delivering electrical stimulation to the vagus nerve. Further, a need exists for improved electrical signals that increase the efficacy of VNS.

SUMMARY OF THE INVENTION

In one embodiment, the invention includes a method of treating a medical condition by detecting a portion of the QRS wave of the patient's cardiac signal and after detecting the portion of the QRS wave, delivering a microburst comprising 2 to 20 electrical pulses to the patient's vagus nerve. Each of

the microbursts may have duration of less than about 100 milliseconds. In particular embodiments, the interpulse intervals separating the pulses are about 3 milliseconds to about 12 milliseconds. In alternate embodiments, the interpulse intervals are less than about 40 milliseconds. In various embodiments, the sum of the interpulse intervals is less than about 40 milliseconds, and in further embodiments, less than about 60 milliseconds. In further embodiments, the method includes waiting a predetermined delay period after the detection of the portion of the QRS wave before generating the microburst.

In another embodiment, the invention includes an exogenous electrical signal delivered to a patient's vagus nerve and adapted to treat a medical condition present in the patient by enhancing the vagal evoked potential in the patient's brain. The exogenous electrical signal includes a series of microbursts each having about 2 to about 20 electrical pulses. In some embodiments, the exogenous electrical signal includes a series of microbursts each having a duration less than about one second. The invention also includes an implantable device configured to apply the inventive exogenous electrical signal.

In further embodiments, the microbursts of the exogenous electrical signal may be synchronized with the R wave portion of the patient's cardiac cycle. In particular embodiments, each of the microbursts of the exogenous electrical signal occur after a selected R wave portion. In various embodiments, each of the microbursts occurs less than about 1000 milliseconds after the selected R wave portion. The pulses of the microbursts may be spaced to simulate the endogenous afferent activity occurring at a particular time in the cardiac cycle. Further, each of the microbursts may be delayed relative to the selected R wave portion to simulate the endogenous afferent activity occurring at a particular time in the cardiac cycle. In various embodiments, the delay has a duration less than about 500 milliseconds. In further embodiments, the delay has a duration less than about 1000 milliseconds.

In various embodiments, each of the microbursts occurs after an R-R interval (i.e., the amount of time between two successive R wave portions in the cardiac signal) having a duration that is shorter than the duration of the previous R-R interval. In further embodiments, the microbursts are delivered to the vagus nerve after the R wave portions occurring during inspiration but not after the R wave portions occurring during expiration.

The invention also includes a method of customizing the exogenous electrical signal to elicit a desired vagal evoked potential in a selected structure of the brain associated with a medical condition. The method includes determining a value of a signal parameter (e.g., pulse width, pulse frequency, an interpulse interval between two of the pulses of the microburst, microburst frequency, a number of microbursts of the series of microburst, a duration of the electrical signal, a number of pulses in the microbursts, etc.), generating an electrical signal having a series of microbursts of 2 to 20 electrical pulses each according to the signal parameter, delivering the electrical signal to the patient's vagus nerve, analyzing an EEG of the patient's brain created during the delivery of the electrical signal to determine the vagal evoked potential observed in the selected structure of the brain, and modifying the value of the signal parameter based on the vagal evoked potential observed in the selected structure of the brain to modify the vagal evoked potential observed therein. In various embodiments, the selected structure of the brain includes the thalamus, striatum, and/or insular cortex.

Embodiments of the invention also include a computer readable medium having computer executable components

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for detecting the QRS wave portion of the cardiac cycle, generating a microburst, and delivering the microburst to the vagus nerve of a patient in response to the detection of the QRS wave portion of the patient's cardiac cycle.

The invention also includes embodiments wherein the patient manually triggers the generation and delivery of the inventive exogenous electrical signal to his/her vagus nerve.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

FIG. 1 illustrates a portion of an ECG trace located above a portion of a trace illustrating an exogenous electrical signal patterned into microbursts that are synchronized with the QRS wave portion of the ECG trace. Each of the microbursts begins after a delay period following the QRS wave portion of the ECG trace.

FIG. 2A illustrates a conventional electrical signal generator that may be modified to deliver an exogenous electrical signal constructed according to the present invention.

FIG. 2B is a block diagram illustrating various components of the electrical signal generator of FIG. 2A.

FIG. 3A is a trace illustrating an exemplary conventional VNS exogenous electrical signal having a series of pulses.

FIG. 3B is a trace of the potential measured in a monkey's thalamus while a portion of the conventional pulse burst of FIG. 3A was applied to the vagus nerve of the monkey.

FIG. 3C is a trace illustrating an exemplary embodiment of an exogenous electrical signal constructed according to the present invention.

FIG. 3D is a trace illustrating the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of four pulses each was applied to the vagus nerve. The inter-microburst interval was about 4 seconds and the interpulse interval was about 3 milliseconds.

FIG. 3E provides nine exemplary traces of the potential measured inside a monkey's thalamus while various exogenous electrical signals were applied to the vagus nerve of the monkey. Each of the traces illustrates the average potential (after 20 microbursts) measured in the monkey thalamus while the exogenous electrical signals was applied to the monkey's vagus nerve. Each of the exogenous electrical signals included a series of microbursts having a selected number of pulses each. The pulses of the microbursts of the exogenous electrical signals of the topmost row have an interpulse interval of 3 milliseconds. The pulses of the microbursts of the exogenous electrical signals of the middle row have an interpulse interval of 6 milliseconds. The pulses of the microbursts of the exogenous electrical signals of the bottom row have an interpulse interval of 9 milliseconds.

FIG. 3F provides three exemplary traces of the potential measured inside a monkey's thalamus while various exogenous electrical signals were applied to the vagus nerve of the monkey. Each of the traces illustrates the average potential (after 20 microbursts) measured in the monkey thalamus while the exogenous electrical signals was applied to the monkey's vagus nerve. All of the exogenous electrical signals included a series of microbursts having three pulses each. The pulses had an interpulse interval of 9 milliseconds. The exogenous electrical signal used to generate the leftmost trace included microbursts separated by an inter-microburst interval of about 6 seconds. The exogenous electrical signal used to generate the middle trace included microbursts separated by an inter-microburst interval of about 2 seconds. The exogenous electrical signal used to generate the rightmost trace included microbursts separated by an inter-microburst interval of about 0.5 seconds.

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FIG. 4A provides four exemplary traces of the potential measured inside a monkey's thalamus while various exogenous electrical signals were applied to the vagus nerve of the monkey. For all of the exogenous electrical signals, the inter-microburst interval was about 4 seconds and the interpulse interval was about 3 milliseconds.

A topmost trace illustrates the average potential (after 20 pulses) measured in the monkey thalamus while a pulse burst having a series of uniformly spaced apart pulses was applied to the monkey's vagus nerve. The spacing between the pulses was about 4 seconds.

A second trace from the top depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of two pulses each was applied to the vagus nerve.

A third trace from the top depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of three pulses each was applied to the vagus nerve.

The bottommost trace depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of four pulses each was applied to the vagus nerve.

FIG. 4B provides five exemplary traces of the potential measured inside a monkey's thalamus while various exogenous electrical signals including microbursts having two pulses each, the microbursts being separated by an inter-microburst interval of about 4 seconds, were applied to the vagus nerve of the monkey. Each of the traces illustrates the average potential (after 20 microbursts) measured in the monkey thalamus while the exogenous electrical signals was applied to the monkey's vagus nerve.

The interpulse interval between the pulses of the microbursts of the exogenous electrical signal was about 40 milliseconds in the topmost trace.

The interpulse interval between the pulses of the microbursts of the exogenous electrical signal was about 20 milliseconds in the trace second from the top.

The interpulse interval between the pulses of the microbursts of the exogenous electrical signal was about 10 milliseconds in the trace third from the top.

The interpulse interval between the pulses of the microbursts of the exogenous electrical signal was about 6.7 milliseconds in the trace fourth from the top.

The interpulse interval between the pulses of the microbursts of the exogenous electrical signal was about 3 milliseconds in the bottommost trace.

FIG. 4C provides five exemplary traces of the potential measured inside a monkey's thalamus while various exogenous electrical signals including microbursts having two pulses each, the pulses of each of the microbursts being separated by an interpulse interval of about 6.7 seconds, were applied to the vagus nerve of the monkey. Each of the traces illustrates the average potential (after 20 microbursts) measured in the monkey thalamus while the exogenous electrical signals was applied to the monkey's vagus nerve.

The inter-microburst interval between the microbursts of the exogenous electrical signal used in the topmost trace corresponded to the microbursts occurring at a microburst frequency of about 10 Hz.

The inter-microburst interval between the microbursts of the exogenous electrical signal used in the trace second from the top corresponded to the microbursts occurring at a microburst frequency of about 3 Hz.

The inter-microburst interval between the microbursts of the exogenous electrical signal used in the trace third from the top corresponded to the microbursts occurring at a microburst frequency of about 1 Hz.

The inter-microburst interval between the microbursts of the exogenous electrical signal used in the trace fourth from the top corresponded to the microbursts occurring at a microburst frequency of about 0.3 Hz.

The inter-microburst interval between the microbursts of the exogenous electrical signal used in the bottommost trace corresponded to the microbursts occurring at a microburst frequency of about 0.25 Hz.

FIG. 5 illustrates a system for using a conventional EEG device to optimize an exogenous electrical signal used for VNS stimulation according to the present disclosure.

FIG. 6 provides an exemplary EEG illustrating the vagal evoked potential elicited by an exogenous electrical signal constructed according to the present invention.

FIG. 7 illustrates an exemplary embodiment of an electrical signal generator programming and/or reprogramming device for use with the electrical signal generator of FIG. 2A-2B.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides novel techniques, alone or in combination, to improve the efficacy of VNS used in the treatment of a variety of medical conditions, including disorders of the nervous system, such as epilepsy and depression. The following disclosure describes various embodiments of a novel method and its associated apparatus for improving VNS therapies. According to the present disclosure, these novel techniques are particularly useful for treating epilepsy and depression. However, it is envisioned that these same novel techniques may be used to treat a variety of disorders and conditions that include a physiological relationship to the nervous system, such as neuropsychiatric disorders, eating disorders/obesity, traumatic brain injury/coma, addiction disorders, dementia, sleep disorders, pain, migraine, endocrine/pancreatic disorders (including but not limited to diabetes), motility disorders, hypertension, congestive heart failure/cardiac capillary growth, hearing disorders, angina, syncope, vocal cord disorders, thyroid disorders, pulmonary disorders, and reproductive endocrine disorders (including infertility). Thus, based on the aforementioned relationship to the nervous system, these disorders and conditions, including epilepsy and depression, are collectively referred to herein as disorders of the nervous system, even if not conventionally described as such.

One of the novel techniques includes synchronizing portions of an exogenous electrical signal with the endogenous afferent activity of the vagus nerve, primarily the endogenous afferent activity originating from receptors in the heart and lungs. Stimulating the vagus nerve in synchrony with endogenous vagal rhythms, in particular with cardiac cycle and heart rate variability (HRV), enhances therapeutic efficacy of VNS.

In the prior art, the exogenous electrical signal applied to the vagus nerve during conventional VNS is often referred to as a pulse burst. The pulse burst typically includes a series of uniformly spaced apart substantially identical pulses, i.e., a simple pulse train. The VNS applied to treat disorders of the nervous system may include multiple pulse bursts separated by an interburst delay.

An individual pulse burst may be triggered automatically or manually. In many prior art devices, a pulse burst may be triggered by the detection of a medical event such as a seizure,

or may be triggered manually by the user or a medical professional. Alternatively, pulse bursts may occur at regular intervals separated by a predetermined interburst delay. Typically, the interburst delay is about five minutes, 30 minutes, or 60 minutes.

The pulses of the conventional VNS pulse bursts are applied asynchronously, i.e., asynchronous with both the cardiac and lung cycles. As mentioned above, conventional VNS is generally applied every 5 minutes in a 7 second to one minute pulse burst (see FIG. 3A for a portion of an exemplary burst) of uniformly spaced apart pulses having an pulse current amplitude of about 0.5 mA to about 2.0 mA. The pulses are delivered at about 20 Hz to about 50 Hz. Each of the pulses may have a width of about 0.5 milliseconds. While monophasic pulses are generally used, biphasic pulses may also be used. As used herein, the term "pulses" refers to both monophasic and biphasic pulses.

In the present invention, the pulses within a pulse burst are patterned or otherwise organized to improve and/or optimize stimulation of the vagus nerve and/or structures of the brain in communication therewith. The natural endogenous afferent activity in the left and right vagus nerves predominantly occurs immediately following each cardiac contraction and during each inspiration. Further, the timing of the endogenous afferent activity in the left and right vagus nerves varies with heart rate, breathing rate, and emotional state. However, because the left and right vagus nerves innervate different portions of the heart, the timing of the afferent activity in the left vagus nerve may differ from the timing of the afferent activity in the right vagus nerve. Consequently, the patterning of the pulse burst may be different for the right and left vagus nerves. As is appreciated by those of ordinary skill in the art, the pulse burst is generally applied to the left vagus nerve because VNS stimulators implanted on the right side applying a pulse burst to the right vagus nerve are associated with an increase in patient mortality. As used herein, the term "vagus nerve" may refer to either the left or right vagus nerve.

According to one aspect of the present invention, a novel exogenous electrical signal is applied to the vagus nerve. The novel exogenous electrical signal is configured to augment the natural endogenous afferent activity in the vagus nerve by timing the pulses within a pulse burst in an improved and more effective manner. In particular embodiments, as will be described in detail below, the pulses within the pulse burst may be organized into sub-bursts or microbursts (each having about 2 to about 20 pulses) that are synchronized with the endogenous afferent activity in the vagus nerve to augment the endogenous afferent activity therein.

Referring to FIG. 1, a trace 100 of a portion of an exemplary embodiment of the novel exogenous electrical signal is provided. Located above the trace 100 in FIG. 1, an exemplary electrocardiogram (ECG) trace 120 depicting cardiac activity detected by an electrocardiograph (not shown) is provided. The novel exogenous electrical signal includes a pulse burst 130 organized into a series of microbursts 170. Each of the microbursts 170 is synchronized with a portion of the cardiac cycle depicted in the ECG trace 120. In particular, each of the microbursts 170 is synchronized with the QRS wave portion 174 of the ECG trace 120, so that endogenous cardiac-related and respiration-related vagal afferent activity is augmented by the microbursts 170 of the exogenous electrical signal.

As illustrated in FIG. 1, each of the microbursts 170 may be triggered by an R-wave portion 176 of the QRS wave portion 174. Without being bound by theory, it is believed that synchronizing the application of the microbursts 170 of the exogenous electrical signal to the vagus nerve with the detection of

the R-wave portion **176** of the patient's cardiac cycle may increase the efficacy of VNS therapy by entraining the exogenous electrical signal with the endogenous cyclic facilitation of central vagal afferent pathways. Each of the microbursts **170** begins after the elapse of a delay period, which comprises a variable time period that may range, e.g., from about 10 milliseconds to about 1000 milliseconds following detection of the R-wave portion **176**. In various embodiments, the delay period may be less than about 10 milliseconds. Further, in some embodiments, the delay period may be about 10 milliseconds to about 500 milliseconds or about 10 milliseconds to about 800 milliseconds. In further embodiments, the delay period is less than 1000 milliseconds. In other embodiments, the delay period may be omitted. Each of the delay periods may comprise a predetermined duration such as about 10 milliseconds, or may comprise a random time duration within a predetermined minimum and maximum time duration, e.g., a random time duration from about 10 milliseconds to about 1000 milliseconds. Further, as will be described below, the duration of the delay period preceding each microburst **170** may be determined empirically.

For example, the leftmost (first) microburst **170** begins after a delay period "D1," the next (or second) microburst **170** begins after a delay period "D2," and the third microburst **170** begins after a delay period "D3." The delay period "D1" may be shorter than the delay periods "D2" and "D3." Additionally, the delay period "D2" may be shorter than the delay period "D3." In alternate embodiments, the delay periods "D1," "D2," and "D3" may be substantially identical. In further embodiments, the delay period "D1," may be larger than delay period "D2," which may be larger than delay period "D3." Embodiments wherein each of the delay periods "D1," "D2," and "D3" is selected randomly within a specified range of delay values or determined empirically are also within the scope of the present invention. As will be appreciated by those of skill in the art, still further embodiments of the present invention may include a variety of delay period combinations that can be identified and implemented by routine experimentation. Each of these is considered to be within the scope of the present invention. While three delay periods have been described with respect to FIG. 1, it is apparent to those of ordinary skill that a delay period may precede each microburst of a pulse burst and the duration of the delay period may be determined empirically or randomly.

In various embodiments, the synchronization of the exogenous electrical signal further comprises not providing pulses during selected portions of the cardiac cycle, such as periods in the opposite half of the cardiac and respiratory duty cycles, when the central pathways are inhibited. Again without being bound by theory, it is believed that pulses applied to the vagus nerve during the opposite half of the cardiac and respiratory duty cycles are less effective because endogenous signals in this part of the cardiac and/or respiratory cycles are less significant, in terms of their information content, for modulating those portions of the brain relevant to homeostasis mechanisms implicated in medical conditions such as epilepsy and depression. Thus, at least a portion of the asynchronous exogenous electrical signal delivered by current stimulation algorithms, such as conventional VNS, may be therapeutically irrelevant.

Because the exogenous electrical signal is typically delivered by an implanted device powered by a battery, the delivery of irrelevant signals may result in unnecessary battery depletion. Further, the pulse burst sometimes causes the patient's vocal cords to contract causing his/her voice to become hoarse, which is uncomfortable and makes talking difficult. Sometimes, the pulse burst causes neck pain and

may cause cardiac problems. Therefore, reducing the number of pulses may contribute to patient comfort and/or safety.

Synchronizing the microbursts **170** of the exogenous electrical signal with each individual QRS wave portion **174** also tracks the natural variability in vagal afferent activity that occurs during breathing and emotional shifts. This heart rate variability (HRV) is a function of respiration and efferent sympathovagal tone. During inspiration, the heart rate accelerates and during expiration it decelerates. Thus, an R-R interval (i.e., the time that elapses between successive R wave portions **176**) appearing in the ECG is shorter during inspiration and longer during expiration, producing HRV. HRV is also known as respiratory sinus arrhythmia. Additionally, it is well established that a larger HRV is associated with greater physical health, including greater immune function, lower risk of cardiac arrhythmia, and better mood, than a smaller HRV.

HRV is greatly increased during meditation, and HRV is increased easily by slow, paced breathing. Synchronizing the microbursts **170** of the exogenous electrical signal with each QRS wave portion **174** of the cardiac cycle utilizes and accentuates the positive association of HRV with overall bodily health. Further, it helps ensure that the microbursts **170** of the exogenous electrical signal are synchronized with variances in the cardiac cycle. Consequently, it may be beneficial for the patient to begin paced breathing during the pulse burst. Further, it may improve the efficacy of the exogenous electrical signal if the pulse burst is triggered while the patient is performing paced breathing.

Referring to FIG. 2A-2B, a suitable electrical signal generator **200**, such as a VNS stimulator, known in the art has one or more electrodes **220A** and **220B** coupled to the vagus nerve for delivering electrical pulses thereto. In embodiments wherein the microbursts of the exogenous electrical signal are synchronized with the cardiac cycle, optionally, the electrical signal generator **200** has the capacity to detect cardiac signals and produce an ECG trace for the purpose of avoiding the deliverance of conventional VNS in the event of cardiac arrest. In other words, the suitable electrical signal generator **200** for use with the present invention may include one or more sensors, such as sensing electrodes **210A** and **210B** positioned to detect cardiac electrical signals, and the onboard capability of analyzing those signals. In particular, the electrical signal generator **200** may be capable of identifying the R wave portion of the cardiac signal. In alternative embodiments, the sensor(s) may include an acoustic device configured to detect the cardiac cycle.

In embodiments wherein the microbursts of the exogenous electrical signal are synchronized with the cardiac cycle, the electrical signal generator **200** may be modified or programmed to deliver the novel exogenous electrical signal. The modifications include replacing a more common open-loop or non-feedback stimulation system with a feedback system utilizing one or more sensing electrodes **210A** and **210B** to detect the QRS wave portion **174** of the ECG trace **120** (see FIG. 1). The modification of the electrical signal generator **200** is effected by programming the electrical signal generator **200** to initiate a microburst **170** after the elapse of the delay period, such as delay period "D1," delay period "D2," or delay period "D3," following the detection of the QRS wave portion **174**. Again, while three exemplary delay periods have been described, a delay period may precede each microburst and such embodiments are within the scope of the present invention. Further, embodiments in which no delay period precedes a microburst are also within scope of the present invention. As is apparent to those of ordinary skill in the art, embodiments of the electrical signal generator **200**

that have the feedback system for detecting the QRS wave portion 174 without modification are also within the scope of the present invention.

FIG. 2B is a block diagram of various components of the electrical signal generator 200. The electrical signal generator 200 may include a programmable central processing unit (CPU) 230 which may be implemented by any known technology, such as a microprocessor, microcontroller, application-specific integrated circuit (ASIC), digital signal processor (DSP), or the like. The CPU 230 may be integrated into an electrical circuit, such as a conventional circuit board, that supplies power to the CPU 230. The CPU 230 may include internal memory or memory 240 may be coupled thereto. The memory 240 is a computer readable medium that includes instructions or computer executable components that are executed by the CPU 230. The memory 240 may be coupled to the CPU 230 by an internal bus 250.

The memory 240 may comprise random access memory (RAM) and read-only memory (ROM). The memory 240 contains instructions and data that control the operation of the CPU 230. The memory 240 may also include a basic input/output system (BIOS), which contains the basic routines that help transfer information between elements within the electrical signal generator 200. The present invention is not limited by the specific hardware component(s) used to implement the CPU 230 or memory 240 components of the electrical signal generator 200.

The electrical signal generator 200 may also include an external device interface 260 permitting the user or a medical professional to enter control commands, such as a command triggering the delivery of the novel exogenous electrical signal, commands providing new instructions to be executed by the CPU 230, commands changing parameters related to the novel exogenous electrical signal delivered by the electrical signal generator 200, and the like, into the electrical signal generator 200. The external device interface 260 may include a wireless user input device. The external device interface 260 may include an antenna (not shown) for receiving a command signal, such as a radio frequency (RF) signal, from a wireless user input device such as a computer-controlled programming wand 800 (see FIG. 7). The electrical signal generator 200 may also include software components for interpreting the command signal and executing control commands included in the command signal. These software components may be stored in the memory 240.

The electrical signal generator 200 includes a cardiac signal interface 212 coupled to sensing electrodes 210A and 210B for receiving cardiac electrical signals. The cardiac signal interface 212 may include any standard electrical interface known in the art for connecting a signal carrying wire to a conventional circuit board as well as any components capable of communicating a low voltage time varying signal received from the sensing electrodes 210A and 210B through an internal bus 214 to the CPU 230. The cardiac signal interface 212 may include hardware components such as memory as well as standard signal processing components such as an analog to digital converter, amplifiers, filters, and the like.

The electrical signal generator 200 includes an exogenous electrical signal interface 222 coupled to electrodes 220A and 220B for delivering the exogenous electrical signal to the vagus nerve. The exogenous electrical signal interface 222 may include any standard electrical interface known in the art for connecting a signal carrying wire to a conventional circuit board as well as any components capable of communicating a low voltage time varying signal generated by the CPU 230 or a signal generating device controlled by the CPU 230 to the electrodes 220A and 220B through an internal bus 252. The

exogenous electrical signal interface 222 may include hardware components such as memory as well as standard signal processing components such as a digital to analog converter, amplifiers, filters, and the like.

The various components of the electrical signal generator 200 may be coupled together by the internal buses 214, 250, 252, and 254. Each of the internal buses 214, 250, 252, and 254 may be constructed using a data bus, control bus, power bus, I/O bus, and the like.

The electrical signal generator 200 may include instructions 280 executable by the CPU 230 for processing and/or analyzing the cardiac electrical signals received by the sensing electrodes 210A and 210B. Additionally, the electrical signal generator 200 may include instructions 280 executable by the CPU 230 for generating an exogenous electrical signal delivered to the vagus nerve by the electrodes 220A and 220B. These instructions may include computer readable software components or modules stored in the memory 240. The instructions 280 may include a Cardiac Signal Monitoring Module 282 that generates a traditional ECG trace from the cardiac electrical signals. The Cardiac Signal Monitoring Module 282 may record the ECG trace in the memory 240.

As is appreciated by those of ordinary skill in the art, generating an ECG trace from an analog cardiac electrical signal may require digital or analog hardware components, such as an analog to digital converter, amplifiers, filters, and the like and such embodiments are within the scope of the present invention. In one embodiment, some or all of these components may be included in the cardiac signal interface 212. In an alternate embodiment, some or all of these components may be implemented by software instructions included in the Cardiac Signal Monitoring Module 282. The Cardiac Signal Monitoring Module 282 may include any method known in the art for generating an ECG trace from a time varying voltage signal.

As mentioned above, the unmodified electrical signal generator 200 monitors cardiac electrical signals for the purposes of detecting a cardiac arrest. The Cardiac Signal Monitoring Module 282 may be modified to include instructions for detecting or identifying the R wave portion of the ECG trace. The R wave portion of the ECG trace may be detected using any method known in the art. While the electrical signal generator 200 has been described as having the Cardiac Signal Monitoring Module 282, embodiments in which the functionality of the Cardiac Signal Monitoring Module 282 is performed by more than one software component are within the scope of the present invention.

The unmodified electrical signal generator 200 generates the exogenous electrical signal used by conventional VNS. The instructions 280 include a Signal Generation Module 284 for instructing the CPU 230 how and when to generate the conventional VNS exogenous electrical signal and deliver it to the vagus nerve via the electrodes 220A and 220B. The Signal Generation Module 284 may be modified to generate the inventive novel exogenous electrical signal. Specifically, the Signal Generation Module 284 may be modified to include instructions directing the CPU 230 to synchronize the microbursts of the exogenous electrical signal with the R wave portion of the ECG trace. The Signal Generation Module 284 may determine the values of the various parameters used to define the novel exogenous electrical signal based on simulating the endogenous afferent activity of the vagus nerve as described herein. Alternatively, the values of the various parameters may be stored in the memory 240 and used by the Signal Generation Module 284 to generate the novel exogenous electrical signal. The various parameters may be entered into the memory 240 by the external device

interface **260** which permits the user or medical professional to enter control commands, including commands changing parameters related to the novel exogenous electrical signal delivered by the electrical signal generator **200**, and the like, into the electrical signal generator **200**.

While the electrical signal generator **200** has been described as having the Signal Generation Module **284**, embodiments in which the functionality of the Signal Generation Module **284** is performed by more than one software component are within the scope of the present invention.

Examples of suitable electrical signal generators for use with the present invention include a model 103 VNS stimulator (formally referred to as the Gen39) produced by Cyberonics, Inc. (Houston, Tex.), model 104 VNS stimulator also produced by Cyberonics, Inc., and the like. The analog recording and ECG recognition capacity of these VNS stimulators enable their onboard processor to be programmed to produce pulse bursts of vagal stimulation having the desired parameters at variable delay periods following the detection of the R-wave of the ECG. The delay periods may comprise a predetermined, programmable duration such as about 10 milliseconds, or may comprise a random time duration within a predetermined programmable minimum and maximum time duration, e.g., a random time duration from about 10 milliseconds to about 1000 milliseconds. The predetermined, programmable duration(s) of the delay period(s) may be determined empirically using methods described below.

While a relatively sophisticated embodiment of the electrical signal generator **200** is described above, those of ordinary skill appreciate that simpler devices, such as a device configured to deliver the exogenous electrical signal asynchronously (i.e., an exogenous electrical signal having microbursts that are not synchronized with the cardiac cycle) are also within the scope of the present invention. The electrical signal generator **200** may provide an asynchronous exogenous electrical signal having microbursts spaced at regular or variable intervals. For example, the microbursts may occur at least every 100 milliseconds or at the microburst frequency of about 0.25 Hz to about 10 Hz. The pulses within the microbursts may be spaced at regular or variable intervals. Further, less sophisticated embodiments of the electrical signal generator **200** include electrical signal generators that are pre-programmed with the exogenous electrical signal parameters (e.g., pulse width, pulse frequency, interpulse interval (s), microburst frequency, number of pulses in the microbursts, etc.) before implementation and may retain those pre-programmed parameter values throughout the functional life of the electrical signal generator. Alternatively, electrical signal generators configured to generate an asynchronous exogenous electrical signal may be programmable after implementation. For example, the computer-controlled programming wand **800** (see FIG. 7) may be used in the manner described above to program such electrical signal generators. As is readily apparent to those of ordinary skill, the present invention is not limited by the particular electrical signal generator used to generate the inventive exogenous electrical signal.

In one aspect, the microbursts of the exogenous electrical signal may be delivered following every detected R-wave occurring within a predetermined pulse burst period, i.e., the period of time during which the exogenous electrical signal is generated. In another embodiment, the microbursts may be applied to the vagus nerve only during the inspiratory phase. This may be implemented by programming the electrical signal generator **200** to apply a microburst only on the shortening R-R intervals during HRV, i.e., only on an R-wave having an R-R interval less than the preceding R-R interval,

or less than a moving average for several R-R intervals, e.g., less than a 5 or 10 R-R interval moving average. In further embodiments, the electrical signal generator **200** may include a sensor, such as a strain gauge or acoustic device, that detects various biometric parameters such as heartbeat and the respiratory cycle. For example, a strain gauge may be used to determine inspiration is occurring by identifying when the chest is expanding. The invention is not limited by the method used to determine inspiration is occurring, the R-R interval, and/or whether the R-R intervals are shortening for the purposes of determining inspiration is occurring.

The timing parameters defining how the microbursts of the exogenous electrical signal are synchronized with the cardiac cycle for maximal therapeutic efficacy may be determined empirically, and according to particular embodiments, are individually optimized for each patient (as described below). In alternate embodiments, patients may perform paced breathing, e.g., taking a breath at a frequency of about 0.1 Hz, during periods when the exogenous electrical signal is being delivered to the vagus nerve, to facilitate or increase the amount of HRV.

In further embodiments, the various parameters of the cardiac cycle synchronized exogenous electrical signal may be varied, including without limitation the duration of the pulse burst, the delay period(s) following R-wave detection, the number of pulses comprising a microburst, the interpulse interval (i.e., the amount of time separating one pulse from an adjacent pulse), and the inter-microburst interval (i.e., the amount of time between successive microbursts). Further, these parameters may be selectively associated with particular R-waves of the respiratory cycle, depending on the length of each preceding R-R-interval. In various embodiments, these parameters are empirically optimized for each patient.

In another aspect of the present invention, a method of providing an exogenous electrical signal capable of inducing a much larger vagal evoked potential (VEP) than that induced by conventional VNS is provided. The exogenous electrical signal provided to the vagus nerve comprises a pulse burst including a series of microbursts. As described above the inter-microburst interval may be determined by the cardiac cycle.

An example of a portion of a pulse burst **300** used in conventional VNS may be viewed in FIG. 3A. The pulse burst **300** includes a plurality of uniformly spaced apart pulses **302** occurring about every 20 milliseconds to about every 50 milliseconds, i.e., occurring at a frequency of about 20 Hz to about 50 Hz. A conventional pulse burst, such as pulse burst **300** may have a pulse burst duration of about 7 seconds to about 60 seconds (resulting in a pulse burst having from about 140 to about 3000 pulses or more). Each pulse **302** may have a width or duration of about 50 microseconds to about 1000 microseconds (μ sec) and a pulse current of about 0.1 mA to about 8 mA.

The pulse burst **300** may be separated from a pulse burst identical to pulse burst **300** by an interburst interval of about 5 min. Sometimes, an interburst interval of about 30 min. or about 60 min. is used. In further implementations, the pulse burst **300** is triggered by the onset of a medical event, such as a seizure, or is triggered by the user or a medical professional. In such embodiments, the interburst interval varies.

FIG. 3B provides a trace **304** of the potential measured in the monkey thalamus while the conventional pulse burst **300** (see FIG. 3A) of uniformly spaced pulses **302** having an interpulse interval of 4 seconds was applied to the vagus nerve. The trace **304** shows the potential inside the thalamus immediately after each of the pulses **302** is delivered to the vagus nerve. An increased VEP **305** occurs after the first pulse

302. However, as illustrated by FIG. 3B, little to no increased VEP is observed after the successive pulses 302 in the series. The average potential inside the thalamus observed over 20 pulses is provided by a topmost trace 320 in FIG. 4A. The VEP is the difference between a minimum average potential in the trace 320 observed after an averaged pulse portion 303 of the trace 320 and a maximum average potential in the trace 320 observed after the averaged pulse portion 303 of the trace 320. However, as illustrated in the trace 320, the minimum and the maximum potentials are not clearly identifiable.

Referring to FIG. 3C, a portion of a pulse burst 400 of the exogenous electrical signal constructed in accordance with the present invention is provided. As is apparent to those of ordinary skill, unlike the uniformly spaced pulses 302 of the pulse burst 300, the pulses 402 and 404 of the pulse burst 400 are patterned or structured within the pulse burst 400. Specifically, the pulses 402 and 404 are arranged into microbursts 410A, 410B, and 410C. In the embodiment depicted in FIG. 3C, each of the microbursts 410A, 410B, and 410C includes the pulse 402 followed by the pulse 404. Each of the individual pulses 402 and 404 in the pulse burst 400 resemble the pulses 302 of the conventional VNS pulse burst 300 and have a pulse width of about 50 microseconds to about 1000 microseconds (μsec) and a pulse current of about 0.25 mA to about 8 mA. In particular embodiments, the pulse current is less than about 2 mA.

While the individual pulses 402 and 404 in the pulse burst 400 resemble the pulses 302 of the conventional VNS pulse burst 300 (i.e., each has a pulse width of about 50 microseconds to about 1000 microseconds (μsec) and a pulse current of about 0.25 mA to about 8 mA) the number of pulses 402 and 404 in the pulse burst 400 is markedly smaller than the number of pulses 302 in the pulse burst 300, assuming the pulse burst 400 has the same duration as the pulse burst 300. As mentioned above, the conventional pulse burst 300 may have a pulse burst duration of about 7 seconds to about 60 seconds and a pulse frequency of about 20 Hz to about 50 Hz, resulting in a pulse burst having from about 140 to about 3000 pulses or more. If the pulse burst 400 has a duration of about 7 seconds to about 60 seconds, and the microbursts are delivered every 0.5 seconds, roughly corresponding to the interval between heart beats during inspiration, the pulse burst 400 will have about 30 pulses to about 242 pulses.

As mentioned above, reducing the number of pulses delivered to the vagus nerve may help prolong battery life as well as improve patient comfort and safety. Further, patterning the pulses of the pulse burst 400 into microbursts, such as microbursts 410A, 410B, and 410C increases the VEP observed in the brain. Because the VEP is increased, the current amplitude may be reduced, further increasing patient comfort and/or safety. The increased VEP may also improve the therapeutic effects of the exogenous electrical signal.

Referring to FIG. 3D, a trace 306 illustrating the average potential inside the monkey thalamus observed over a series of 20 microbursts, each having a series of four pulses with a 3 milliseconds interpulse interval separating the pulses, is provided. The microbursts of FIG. 3D are separated by a 4 second inter-microburst interval. The VEP is the difference between a minimum 307 in the trace 306 observed after an averaged microburst portion 309 of the trace 306 and a maximum 308 in the trace 306 observed after the averaged microburst portion 309 of the trace 306. The difference between the minimum 307 and the maximum 308 of the trace 306 is clearly larger than the difference between the unidentifiable minimum and the unidentifiable maximum of the trace 320 (see FIG. 4A and the pulse intervals after the third pulse in FIG. 3B). Therefore, without changing any param-

eters other than the number of pulses delivered every 4 sec., i.e., delivering a microburst instead of a single pulse, the VEP potential can be increased or enhanced.

The pulses 402 and 404 within the first microburst 410A are separated by an interpulse interval "P1A." The pulses 402 and 404 within the second microburst 410B are separated by an interpulse interval "P1B." The pulses 402 and 404 within the third microburst 410C are separated by an interpulse interval "P1C." In most cases, the interpulse intervals "P1A," "P1B," and "P1C" separating the pulses 402 and 404 are shorter than the interpulse intervals between the pulses 302 used in conventional VNS therapy. The first interpulse interval "P1A" may range from about one millisecond to about 50 milliseconds. Typically, the first interpulse interval "P1A" may range from about 2 milliseconds to about 10 milliseconds. In some embodiments, Typically, the first interpulse interval "P1A" may range from about 3 milliseconds to about 10 milliseconds. In various embodiments, the interpulse interval "P1B" may be substantially equal to the interpulse interval "P1A." Subsequent interpulse intervals occurring after the interpulse interval "P1B," such as interpulse interval "P1C," may be substantially equal to the interpulse interval "P1B." In alternate embodiments, the interpulse interval "P1A" may be larger than the interpulse interval "P1B," which may be larger than the interpulse interval "P1C." In further embodiments, the interpulse interval "P1A" may be smaller than the interpulse interval "P1B," which may be smaller than the interpulse interval "P1C." In various embodiments, the interpulse intervals "P1A," "P1B," and "P1C" may be selected randomly from a predetermined range of interpulse interval values. In further embodiments, the interpulse intervals may be variable and determined empirically, as described below.

The first microburst 410A is separated from the microburst 410B by an inter-microburst interval "P2." Each microburst may be considered an event occurring at a microburst frequency (i.e., the inverse of the sum of the inter-microburst interval "P2" and the duration of the microburst). The microburst frequency may range from about 0.25 Hz to about 10 Hz. It may be beneficial to use a microburst frequency that approximates the R-R cycle of the patient.

In various embodiments, the pulses within a microburst may be patterned or structured. For example, referring to FIG. 1, the portion of the pulse burst 130 is provided. The pulse burst 130 includes five microbursts 170, each triggered by the R-wave portion 176 of the cardiac cycle depicted in the ECG trace 120. Each microburst 170 includes four pulses 182, 184, 186, and 188. The first pulse 182 begins after the predetermined delay time "D1" has elapsed following the identification of the R-wave portion 176. The pulse 184 follows the pulse 182 after a first interpulse delay has elapsed. Then, after a second interpulse interval, the pulse 186 is generated. Finally, after a third interpulse interval, the pulse 188 is generated. In the embodiment depicted in FIG. 1, the interpulse intervals increase in duration along the series of pulses. However, the interpulse intervals may be determined empirically and individualized for each patient. While each microburst 170 in FIG. 1 has only four pulses, microbursts 170 having 2 to 20 pulses, and consequently 1 to 19 interpulse intervals, are within the scope of the present invention. In some embodiments, the microbursts 170 may have 2 to 15 pulse, or alternatively, 3 to 6 pulses.

In various embodiments, the pulse burst 400 may be separated from a pulse burst identical to pulse burst 400 or a dissimilar pulse burst by an interburst interval of about 5 minutes to about 240 minutes. Alternatively, the interburst interval may be about 200 milliseconds to about 24 hours. In

further embodiments, the pulse burst is applied continuously. The pulse burst may have a duration of about 100 milliseconds to about 60 minutes. In various embodiments, the pulse burst duration is determined empirically for a particular patient and/or medical condition. In further embodiments, the pulse burst **400** is triggered by the onset of a medical event, such as a seizure, or is triggered by the user or a medical professional. In such embodiments, the interburst interval varies. Optionally, the pulse burst **400** may be terminated automatically by the onset of a medical event, such as cardiac arrest, or manually the user or a medical professional. In such embodiments, the pulse burst duration varies.

Pulses, such as pulses **182**, **184**, **186**, and **188**, arranged into microbursts, such as microburst **170**, are capable of evoking an enhanced vagal evoked potential (eVEP) in the patient's brain that is significantly greater than an VEP evoked by conventional VNS (see FIG. 3A). However, this eVEP may attenuate as the number of pulses within a microburst increases beyond an optimal number of pulses. Framed a little differently, the eVEP attenuates as the microburst duration increases beyond an optimal duration. Thus, for example, where a microburst exceeds 2 pulses to 5 pulses, the eVEP begins to diminish, and if more than 20 pulses are provided, the eVEP essentially disappears. This may be observed in FIG. 3E.

Referring to the top row of FIG. 3E, traces **370**, **372**, and **374** illustrate the average potential inside the monkey thalamus averaged over a series of 20 microbursts, each having a series of pulses separated by an interpulse interval of 3 milliseconds. The microbursts of FIG. 3E are separated by a 4 second inter-microburst interval. The number of pulses within the microbursts increase from left to right. In the leftmost trace **370**, the microbursts had 2 pulses each. In the center trace **372**, the microbursts had 5 pulses each. And, in the rightmost trace **374**, the microbursts had 9 pulses each. Again, the VEP observed in each trace, is the difference between a minimum in the trace observed after an averaged microburst portion (appearing at the left of the trace) and a maximum in the trace observed after the averaged microburst portion of the trace. The top row clearly illustrates that using these parameters, microbursts having 5 pulses produce a larger VEP than microbursts having 2 pulses. However, microbursts having 9 pulses produce a smaller VEP than microbursts having 5 pulses.

Referring to the middle row of FIG. 3E, traces **380**, **382**, and **384** illustrate the average potential inside the monkey thalamus averaged over a series of 20 microbursts, each having a series of pulses separated by an interpulse interval of 6 milliseconds. In the leftmost trace **380**, the microbursts had 2 pulses each. In the center trace **382**, the microbursts had 3 pulses each. And, in the rightmost trace **384**, the microbursts had 6 pulses each. The middle row clearly illustrates that using these parameters, microbursts having 3 pulses produce a larger VEP than microbursts having 2 pulses. However, microbursts having 6 pulses produce a smaller VEP than microbursts having 3 pulses.

Referring to the bottom row of FIG. 3E, traces **390**, **392**, and **394** illustrate the average potential inside the monkey thalamus averaged over a series of 20 microbursts, each having a series of pulses separated by an interpulse interval of 9 milliseconds. In the leftmost trace **390**, the microbursts had 2 pulses each. In the center trace **392**, the microbursts had 3 pulses each. And, in the rightmost trace **394**, the microbursts had 5 pulses each. The bottom row clearly illustrates that using these parameters, microbursts having 3 pulses produce

a larger VEP than microbursts having 2 pulses. However, microbursts having 5 pulses produce a smaller VEP than microbursts having 3 pulses.

Referring to the leftmost column of FIG. 3E, traces **370**, **380**, and **390** illustrate the facilitation the first pulse provides to the second pulse of the microburst. The traces **372**, **382**, and **392** in the rightmost column of FIG. 3E illustrate additional facilitation provided by adding additional pulses to the microburst. However, the traces **374**, **384**, and **394** in the rightmost column of FIG. 3E illustrate that if the duration of the microbursts is too long, the microburst extends into an inhibitory period of neural activity reducing the VEP observed in the thalamus of the monkey. Consequently, the VEP may be improved and/or optimized by the selection of the number of pulses of the microbursts.

It may be helpful to define a microburst by its duration rather than the number of pulses. Experimental results related to optimizing microburst duration are illustrated in FIGS. 3E and 4B. For example, ignoring the pulse widths, FIG. 3E illustrates that the VEP begins to decline when the sum of the interpulse intervals within a single microburst exceeds about 30 milliseconds. Consequently, for the monkey, the optimal sum of the interpulse intervals within a single microburst may be less than 30 milliseconds and in some embodiments, less than 20 milliseconds. The data of FIG. 3E further indicates, a range of about 12 milliseconds to about 18 milliseconds may be used. Human beings are larger and have a heart rate that is roughly half (about 180 beats/minute for the monkey and about 70 beats/minute for a human). Therefore, one of ordinary skill will recognize that by doubling the sum of the interpulse intervals, the sum of the interpulse intervals may be converted for use with a human. Based on this rough approximation, for humans, the optimal sum of the interpulse intervals within a single microburst may be less than 80 milliseconds and in some embodiments, the sum may be less than 60 milliseconds. In further embodiments, the sum of the interpulse intervals within a single microburst may be less than about 40 milliseconds and preferably about 12 milliseconds to about 40 milliseconds. In some embodiments, the sum of the interpulse intervals within a single microburst may be about 10 milliseconds to about 80 milliseconds. One of ordinary skill in the art will also recognize alternate methods of converting the sum of the interpulse intervals determined in the experimental monkey data for use with a human and that such embodiments are within the scope of the present invention. Further, the sum of the interpulse intervals for use with a human may be determined empirically using the empirical method described below.

Generally, the microburst duration (i.e., the sum of the interpulse intervals and the pulse widths within a microburst) may be less than about one second. In particular embodiments, the microburst duration may be less than about 100 milliseconds. In particular embodiments, microbursts having a duration of about 4 milliseconds to about 40 milliseconds may be used.

Referring to the top row of FIG. 3F, traces **391**, **393**, and **395** illustrate the average potential inside the monkey thalamus averaged over a series of 20 microbursts, each having a series of pulses separated by an interpulse interval of about 9 milliseconds. The microbursts used to create the traces **391**, **393**, and **395** are separated by about a 6 second, about a 2 second, and about a 0.5 second inter-microburst interval, respectively. While the VEP in the trace **395** is less than the VEP in the other two traces **393**, and **395**, the trace **395** illustrates that the eVEP is present at the rate the QRS wave occurs in the cardiac cycle during inspiration, i.e., about once every 0.5 second. Consequently, microbursts synchronized

with the QRS wave during inspiration may produce eVEP in the thalamus and other brain structures in electrical communication therewith. Other parameters, such as interpulse interval(s), delay period(s), pulse current amplitude, pulse width, pulse burst duration, and the like may be adjusted to improve and/or optimize the VEP.

To maintain the eVEP, the present invention provides a microburst having only a small number of pulses as well as an inter-microburst interval that serves as a period during which the vagus nerve (and/or brain structures in communication therewith) may recover from the microburst. Providing an appropriate inter-microburst interval helps ensure that the succeeding microburst in the pulse burst of the exogenous electrical signal is capable of generating the eVEP. In some embodiments, the inter-microburst interval is as long as or longer than the duration of the microburst. In another embodiment, the inter-microburst interval is at least 100 milliseconds. In further embodiments, the inter-microburst interval may be as long as 4 seconds or 6 seconds. In some embodiments, the inter-microburst interval may be as long as 10 seconds. Each microburst comprises a series of pulses that, in some embodiments, are intended to mimic the endogenous afferent activity on the vagus nerve. In one embodiment, the microburst may simulate the endogenous afferent vagal action, such as the action potentials associated with each cardiac and respiratory cycle.

The central vagal afferent pathways involve two or more synapses before producing activity in the forebrain. Each synaptic transfer is a potential site of facilitation and a non-linear temporal filter, for which the sequence of inter-microburst intervals and/or interpulse intervals within a microburst can be optimized. Without being bound by theory, it is believed that the use of microbursts enhances VNS efficacy by augmenting synaptic facilitation and "tuning" the input stimulus train to maximize the forebrain evoked potential.

FIG. 4A-4C illustrate the effects of modifying the various parameters of the exogenous electrical signal on the VEP measured in the thalamus of a monkey. FIG. 4A illustrates the effects of varying the number of pulses in a microburst. FIG. 4B illustrates the effects of varying the interpulse interval between the pulses of a microburst having only two pulses. FIG. 4C illustrates the effects of varying the inter-microburst interval between adjacent microbursts having only two pulses each.

The topmost trace 320 of FIG. 4A provides the average potential (after 20 pulses) measured in the monkey thalamus while a pulse burst of uniformly spaced apart pulses having an interpulse interval of 4 seconds was applied to the vagus nerve.

A trace 340 of FIG. 4A depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of two pulses each was applied to the vagus nerve. The inter-microburst interval was about 4 seconds and the interpulse interval was about 3 milliseconds. The VEP (i.e., the difference between the minimum and maximum potentials observed after each microburst) is noticeably improved in the trace 340 when compared with the VEP of the trace 320.

A trace 350 depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of three pulses each was applied to the vagus nerve. The inter-microburst interval was about 4 seconds and the interpulse interval was about 3 milliseconds. The VEP is noticeably improved in the trace 350 when compared with the VEP of the trace 340.

A trace 360 depicts the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of four pulses each was applied to the vagus nerve. The inter-microburst interval was about 4 seconds and the interpulse interval was about 3 milliseconds. The VEP is noticeably improved in the trace 360 when compared with the VEP of the trace 350.

Referring to FIG. 4B, the effect of the interpulse interval on the VEP is illustrated. Traces 500, 510, 520, 530, and 540 depict the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of two pulses each, separated by an inter-microburst interval of 4 sec. was applied to the vagus nerve. The interpulse intervals were about 40 milliseconds, about 20 milliseconds, about 10 milliseconds, about 6.7 milliseconds, and about 3 milliseconds for the traces 500, 510, 520, 530, and 540, respectively. The VEP is barely visible in the trace 500. The VEP is noticeably improved in the trace 510 when compared with the VEP of the trace 500. The VEP is noticeably improved in the trace 520 when compared with the VEP of the trace 510. The VEP is noticeably improved in the trace 530 when compared with the VEP of the trace 520. However, the VEP in the trace 540 is noticeably less than the VEP 534 of the trace 530.

Referring to FIG. 4C, the effect of the inter-microburst interval on the VEP is illustrated. Traces 600, 610, 620, 630, and 640 depict the average potential (after 20 microbursts) measured in the monkey thalamus while a pulse burst having microbursts of two pulses each, the pulses being separated by an interpulse interval of 6.7 milliseconds, was applied to the vagus nerve. The inter-microburst intervals corresponded to the microbursts occurring at a microburst frequency of about 10 Hz, about 3 Hz, about 1 Hz, about 0.3 Hz, and about 0.25 Hz for the traces 600, 610, 620, 630, and 640, respectively. The VEP is barely visible in the trace 600. Because the inter-microburst interval was sufficiently short, the trace 600 shows a second microburst artifact 606 to the right of the first microburst artifact 602. The VEP is noticeably improved in the trace 610 when compared with the VEP of the trace 600. The VEP is noticeably improved in the trace 620 when compared with the VEP of the trace 610. The VEP is noticeably improved in the trace 630 when compared with the VEP of the trace 620. However, the VEP in the trace 640 is noticeably less than the VEP in the trace 630.

As depicted in FIG. 4A-4C, the VEP is enormously enhanced (resulting in eVEP) and optimized by using a microburst of pulses (two or more, FIG. 4A) at appropriate interpulse intervals (in this case, 6.7 milliseconds was optimal for the first interpulse interval, shown in FIG. 4B) and at a inter-microburst interval (i.e., microburst frequency) that approximates the R-R cycle (i.e., the frequency at which the R wave portion appears in the ECG trace) of the monkey (in this case, about 0.3 Hz, as shown in FIG. 4C).

The experimental results depicted in FIGS. 3D-3F and 4A-4C were obtained using a pulse burst including microbursts that were not synchronized with the cardiac cycle. In additional experiments, the effect of synchronizing the pulse bursts with the cardiac cycle was shown. Specifically, a single pulse was delivered at various times following every third R-wave. The VEP values obtained were then correlated with respiration. With respect to synchronization with the cardiac cycle, the experiments showed that the largest VEP was obtained when the pulse was delivered within 250 milliseconds after the initiation of a breath (which is accompanied by a decrease in the R-R interval). With respect to the delay period, the experiments showed that the greatest

improvement in the VEP was obtained when the pulse was delivered about 400 milliseconds after the R-wave.

Additionally, the experimental data showed that by timing the pulse properly, an improvement in efficacy on the order of a factor of ten was obtained. Specifically, when the pulse was delivered about 0.5 seconds to about 1.0 second following the initiation of respiration and within 50 milliseconds following the R-wave, the VEP had a peak-to-peak amplitude of about 0.2 mV to about 0.4 mV. In contrast, when the pulse was delivered about 250 milliseconds after the initiation of inspiration and about 400 milliseconds following the R-wave, the VEP had a peak-to-peak amplitude of about 1.2 mV to about 1.4 mV. At maximum, this corresponds to about a seven-fold improvement in the VEP. These data show that by synchronizing the stimulation with respect to the cardiorespiratory cycles of the monkey, the efficacy of the stimulus pulse can be greatly improved over that of asynchronous stimulus delivery. These measurements were made in a monkey under deep anesthesia. Consequently, those of ordinary skill would expect an even greater effect in an awake human.

The use of pairs of pulses is a standard physiological tool for producing central responses by stimulation of small-diameter afferent fibers. However, according to the present invention, a pulse burst including microbursts of pulses having an appropriate sequence of interpulse intervals enormously enhances the effect of VNS. By selecting the appropriate signal parameters (e.g., pulse width, pulse frequency, interpulse interval(s), microburst frequency, microburst duration, number of pulses in the microbursts, etc.), the exogenous electrical signal applied to the vagus nerve may comprise a series of microbursts that each provide an eVEP.

As illustrated in FIGS. 4A and 3E, a microburst duration greater than about 10 milliseconds (corresponding to 4 pulses having an interpulse interval of about 3 milliseconds) produces a maximal eVEP in the thalamus of the monkey and an interpulse interval of about 6 milliseconds to about 9 milliseconds produces maximal facilitation by the first pulse of the second pulse. Accordingly, a brief microburst of pulses with a total duration of about 10 milliseconds to about 20 milliseconds and having an initial interpulse interval of about 6 milliseconds to about 9 milliseconds and subsequent intervals of similar or longer duration may produce an optimal VEP. This is because such microbursts of pulses simulate the pattern of naturally occurring action potentials in the small-diameter afferent vagal fibers that elicit the central response that the present enhanced and optimized therapy is most interested in evoking (see below). Selection of an appropriate inter-microburst interval to separate one microburst from the next may be performed experimentally, although as previously noted, a period of at least 100 milliseconds (preferably at least 500 milliseconds, and more preferably at least one second) and at least equal to the microburst duration may be desirable.

The most effective sequence of interpulse intervals will vary with the patient's HRV (cardiac and respiratory timing) and also between individual patients, and thus, in some embodiments, the parameters of the exogenous electrical signal, such as the number of pulses in a microburst, the interpulse interval(s), the inter-microburst interval(s), the duration of the pulse burst, the delay period(s) between each QRS wave and a microburst, the current amplitude, the QRS waves of the cardiac cycle after which a microburst will be applied, the pulse width, and the like may be optimized for each patient. As a standard microburst sequence for initial usage, a microburst of 2 or 3 pulses having an interpulse interval of

about 5 milliseconds to about 10 milliseconds may be used to approximate the short burst of endogenous post-cardiac activity.

The inter-microburst interval may be determined empirically by providing microbursts with a steadily decreasing inter-microburst interval until the eVEP begins to decline. In some embodiments, the interpulse interval varies between the pulses. For example, the interpulse interval may increase between each successive pulse in the microburst, simulating the pattern of a decelerating post-synaptic potential, as illustrated in FIG. 1. In alternative embodiments, the interpulse intervals may decrease between each successive pulse in the microburst, or may be randomly determined within a pre-selected range, e.g., about 5 milliseconds to about 10 milliseconds. Alternatively, the interpulse interval may remain constant between successive pulses in the microburst (i.e., providing a simple pulse train). Further, in a method described below, the interpulse intervals may be specified between each successive pair of pulses using the VEP determined by an EEG. These modifications to the conventional VNS methodology produce a significant enhancement of VNS efficacy that is applicable to all VNS protocols and to many different medical conditions, including disorders of the nervous system.

As noted above, the stimulation parameters (e.g., interpulse interval(s), inter-microburst interval(s), number of pulses per microburst, etc.) may be individually optimized for each patient. The optimization is accomplished by using surface electrodes to detect a far-field VEP, originating in the thalamus and other regions of the forebrain, and varying the stimulus parameters to maximize the VEP detected. As illustrated in FIG. 5, standard EEG recording equipment 700 and a 16-lead or a 25-lead electrode placement 710 of the EEG surface electrodes 712, such as that typically used clinically for recording somatosensory or auditory evoked potentials, enables the VEP present in the patient's forebrain to be detected, using VNS stimulus microburst timing to synchronize averages of about 8 epochs to about 12 epochs. The EEG recording equipment 700 may be used to produce continuous EEG waveforms 720 and recordings 730 thereof. By testing the effects of varying the parameters of the exogenous electrical signal, the VEP can be optimized for each patient.

The exogenous electrical signal used to deliver VNS is optimized in individual patients by selecting stimulus parameters that produce the greatest effect as measured by EEG surface electrodes 740. The pulse current amplitude and pulse width is first optimized by measuring the size of the VEP elicited by individual pulses (and not microbursts). The number of pulses, interpulse intervals, and inter-microburst intervals are then optimized (using the current amplitude and pulse width determined previously) by measuring the magnitude of the VEP evoked by the microbursts, as well as the effects on de-synchronization in the continuous EEG recordings. It may be desirable to determine the number of pulses first and then determine the interpulse intervals between those pulses. In alternate embodiments, it may be desirable to determine the number of pulses first, followed by the microburst duration, and lastly, the interpulse intervals between the pulses.

Because the large eVEPs recorded in the thalamus, striatum, and insular cortex of the anesthetized monkey and shown in FIG. 4A-4C, are large enough that if evoked in a human patient, the eVEPs are observable in a standard EEG detected using electrodes adjacent to the human patient's scalp, the standard EEG may be used to indicate the effects of modifications to the signal parameters of the exogenous electrical signal. In this manner, the EEG may be used to optimize or tune the signal parameters of the exogenous electrical

signal empirically. For a human patient, this method provides a safe and non-invasive way to customize the various signal parameters for the patient and/or the treatment of the patient's medical condition.

The eVEP recorded in the right thalamus and right striatum is significant for the anti-epileptic effects of VNS, whereas the eVEP recorded in the left insular cortex is most significant for the anti-depression effects of VNS. By using regional EEG localization on the right or left frontal electrodes, the signal parameters of the exogenous electrical signal may be optimized appropriately to achieve an eVEP in the appropriate region of the individual patient's brain. Further, the magnitude of the measured VEP may be appropriately tuned for the patient.

The optimal exogenous electrical signal parameters for eliciting eVEPs from these two areas (right thalamus/striatum and left insular cortex, respectively) may differ. Both eVEPs are identifiable using known EEG recording methods in awake human patients. Therefore, EEG recordings made using these methods may be used to evaluate the eVEP in the appropriate area. The EEG recording may be used to collect samples of the eVEP in the appropriate area(s) and those samples may be used easily for a parametric optimization, in a patient suffering from a disorder of the nervous system such as epilepsy or depression. Similarly, the exogenous electrical signal parameters used for HRV-synchronization may be selected based on their effects on the VEP and on the heart-beat-related evoked potential both of which may be measured using known noninvasive EEG recording methods that use EEG electrodes attached to the patient's scalp.

Referring to FIG. 6, an exemplary EEG is provided. A pair of traces **810** and **812** correspond to the potential present in the left striatum and left insular cortex and a pair of traces **820** and **822** correspond to the potential present in the left striatum and left insular cortex. While the same traces **810**, **812**, **820** and **822** depict the potential present in striatum and insular cortex, the potential in the striatum may be distinguished from the potential in the insular cortex by its timing. Experiments have shown that pulses applied to the vagus nerve reach the parafascicular nucleus in the thalamus in about 18 milliseconds and the basal portion of the ventral medial nucleus in about 34 milliseconds. The parafascicular nucleus then projects the stimulus to the striatum and the basal portion of the ventral medial nucleus projects the stimulus to the insular cortex. Consequently, the potential evoked by the pulse burst in the striatum will appear in the traces **810**, **812**, **820** and **822** before the potential evoked in the insular cortex. By analyzing the traces **810**, **812**, **820** and **822**, the potential inside the striatum and/or the insular cortex may be observed and the signal parameter used to generate those potentials modified to enhance and/or optimize those potentials.

In FIG. 6, the strong VEP shown in traces **820** and **822** corresponding to the right thalamus and the right striatum (or basal ganglia) is associated with the anti-epileptic effects of VNS. As mentioned above, distinguishing the right thalamus from the right insular cortex may be accomplished by analyzing the timing of the eVEP observed in the traces **820** and **822**. The strong VEP shown in traces **810** and **812** corresponding to the left thalamus and left insular cortex is associated with the anti-depression effects of VNS. Traces **830** and **832** in the central portion of the EEG depict a weak VEP in the thalamus. Because the EEG method described is non-invasive, it offers a safe and effective method of enhancing and/or optimizing the therapeutic effects of the exogenous electrical signal.

FIG. 7 illustrates one method of variable programming of the electrical signal generator **200** to optimize the eVEP in the

right thalamus and striatum for epileptic patients, and in the left insula for patients suffering from depression. As shown in FIG. 7, a computer **900** may be coupled to and used to program the computer-controlled programming wand **800**. The programming wand **800** may use radio frequency telemetry to communicate with the electrical signal generator **200** and program the burst duration, number of pulses in a microburst, interpulse interval(s), pulse frequency, microburst duration, inter-microburst interval, pulse width, and current amplitude of the exogenous electrical signal delivered by the electrical signal generator **200** to the vagus nerve of the patient. Using the programming wand **800**, programming may be performed periodically or as needed on an implanted electrical signal generator **200**. This provides the ability to continually optimize and change the exogenous electrical signal delivered by the electrical signal generator **200** depending on the EEG, and to respond to changes therein. Therefore, the present method of using one or more of the above referenced techniques, alone or in combination, significantly enhances and/or optimizes currently available VNS therapies.

Various embodiments of the invention are described above in the Detailed Description. While these descriptions directly describe the above embodiments, it is understood that those skilled in the art may conceive modifications and/or variations to the specific embodiments shown and described herein. Any such modifications or variations that fall within the purview of this description are intended to be included therein as well. Unless specifically noted, it is the intention of the inventors that the words and phrases in the specification and claims be given the ordinary and accustomed meanings to those of ordinary skill in the applicable art(s).

The foregoing description of various embodiments of the invention known to the applicant at this time of filing the application has been presented and is intended for the purposes of illustration and description. The present description is not intended to be exhaustive nor limit the invention to the precise form disclosed and many modifications and variations are possible in the light of the above teachings. The embodiments described serve to explain the principles of the invention and its practical application and to enable others skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed for carrying out the invention.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of this invention. Furthermore, it is to be understood that the invention is solely defined by the appended claims. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least

one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations).

Accordingly, the invention is not limited except as by the appended claims.

The invention claimed is:

1. A method of treating a brain disorder in a patient having a cardiac cycle, a vagus nerve, and a brain, the method comprising:

detecting at least a portion of the cardiac cycle of the patient;

applying to a selected location on the vagus nerve of the patient, in response to having detected the portion of the cardiac cycle of the patient, a pulsed electrical signal configured to increase afferent activity on the vagus nerve to be conducted thereby to the brain to treat the brain disorder, the pulsed electrical signal comprising a plurality of microbursts, wherein each microburst other than a last of the plurality of microbursts is separated from an adjacent microburst by an interburst interval, and at least one interburst interval is varied from at least one other interburst interval, wherein each microburst of the pulsed electrical signal comprises:

from 3 to 6 pulses per microburst;

a plurality of interpulse intervals, each interpulse interval being between adjacent pulses of the microburst, each interpulse interval ranging from about 5 to about 10 milliseconds, wherein at least one interpulse interval of the plurality of interpulse intervals within the microburst is varied from at least one other interpulse interval of the plurality of interpulse intervals within the microburst; and

a microburst duration less than or equal to 100 milliseconds.

2. The method of claim 1, wherein detecting the portion of the cardiac cycle of the patient comprises:

detecting a portion of a QRS complex of patient's cardiac cycle, and

applying the pulsed electrical signal comprises synchronizing an application of the pulsed electrical signal to the vagus nerve of the patient with a QRS complex of the patient's cardiac cycle.

3. The method of claim 1, wherein detecting the portion of the cardiac cycle of the patient comprises detecting an R wave of the patient's cardiac cycle, and wherein applying the pulsed electrical signal comprises applying the pulsed electrical signal to the vagus nerve of the patient after a delay period following detection of each of a plurality of R waves of the patient.

4. The method of claim 3, wherein the delay period comprises from about 10 milliseconds to about 1000 milliseconds following detection of each of the plurality of R waves.

5. The method of claim 4, wherein the delay period comprises from about 10 milliseconds to about 500 milliseconds following detection of each of the plurality of R waves.

6. The method of claim 3, wherein the delay period comprises random time periods within a specified range of delay values.

7. The method of claim 1, wherein each interburst interval is from about 100 milliseconds to about six seconds.

8. The method of claim 1, wherein the plurality of microbursts are applied to the vagus nerve at a microburst frequency of about 10 Hz to about 0.25 Hz.

9. The method of claim 1, further comprising:

utilizing at least one electrode;

utilizing at least one sensor;

utilizing the at least one electrode on the vagus nerve of the patient;

utilizing an electrical signal generator coupled to the electrode;

detecting the portion of the cardiac cycle of the patient using the at least one sensor;

generating the pulsed electrical signal using the electrical signal generator; and

applying the pulsed electrical signal to the at least one electrode.

10. The method of claim 1, wherein the brain disorder is selected from the group consisting of epilepsy, neuropsychiatric disorders including but not limited to depression, eating disorders including obesity, traumatic brain injury, coma, addiction disorders, dementia, sleep disorders, pain, and migraine.

11. The method of claim 1, wherein a sum of the interpulse intervals separating the pulses of each of the microbursts is less than about 60 milliseconds.

12. The method of claim 1, wherein the pulsed electrical signal is applied to augment natural endogenous afferent vagal activity.

13. The method of claim 1, further comprising not providing the pulsed electrical signal during at least the portion of the cardiac cycle of the patient.

14. The method of claim 1, wherein detecting the portion of the cardiac cycle of the patient comprises acoustically detecting at least the portion of the cardiac cycle of the patient.

15. The method of claim 1, further comprising:

detecting an inspiratory phase of a respiratory cycle of the patient;

wherein applying the pulsed electrical signal to the vagus nerve further comprises applying the pulsed electrical signal only during the inspiratory phase of the respiratory cycle of the patient.

16. The method of claim 1, wherein at least one interpulse interval of the plurality of interpulse intervals is selectively varied from at least one other interpulse interval of the plurality of interpulse intervals.

17. The method of claim 1, wherein the interpulse intervals of the pulsed electrical signal vary between each successive pulse of each microburst, and wherein the variation of the interpulse intervals between each successive pulse comprises one of an increase in the interpulse interval between each successive pulse and a decrease in the interpulse interval between each successive pulse.

18. The method of claim 1, wherein varying at least one interpulse interval of the plurality of interpulse intervals of the microburst comprises a first interpulse interval having a duration different from a second interpulse interval.

19. A non-transitory computer readable program storage device encoded with instructions that, when executed by a computer, perform a method, comprising:

detecting at least a portion of the cardiac cycle of the patient;

applying to a selected location on a vagus nerve of the patient, in response to having detected the portion of the cardiac cycle of the patient, a pulsed electrical signal configured to increase afferent activity on the vagus nerve to be conducted thereby to a brain to treat a brain disorder, the pulsed electrical signal comprising a plurality of microbursts, wherein each microburst other than a last of the plurality of microbursts is separated from an adjacent microburst by an interburst interval, and at least one interburst interval is varied from at least one other interburst interval, wherein each microburst of the pulsed electrical signal comprises:

from 3 to 6 pulses per microburst;

a plurality of interpulse intervals, each interpulse interval being between adjacent pulses of the microburst, each interpulse interval ranging from about 5 to about 10 milliseconds, wherein at least one interpulse interval of the plurality of interpulse intervals within the microburst is varied from at least one other interpulse interval of the plurality of interpulse intervals within the microburst; and

a microburst duration less than or equal to 100 milliseconds.

20. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the detecting the portion of the cardiac cycle of the patient comprises detecting a portion of a QRS complex of the patient's cardiac cycle, and wherein the applying the pulsed electrical signal comprises synchronizing an application of the pulsed electrical signal to the vagus nerve of the patient with a QRS complex of the patient's cardiac cycle.

21. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the detecting the portion of the cardiac cycle of the patient comprises detecting an R wave of the patient's cardiac cycle, and wherein applying the pulsed electrical signal comprises applying the pulsed electrical signal to the vagus nerve of the patient after a delay period following detection of each of a plurality of R waves of the patient.

22. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein each interburst interval is from about 100 milliseconds to about six seconds.

23. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the plurality of microbursts are applied to the vagus nerve at a microburst frequency of about 10 Hz to about 0.25 Hz.

24. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the brain disorder is selected from the group consisting of epilepsy, neuropsychiatric disorders including but not limited to depression, eating disorders including obesity, traumatic brain injury, coma, addiction disorders, dementia, sleep disorders, pain, and migraine.

25. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein a sum of the interpulse intervals separating the pulses of each of the microbursts is less than about 60 milliseconds.

26. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the pulsed electrical signal is applied to augment natural endogenous afferent vagal activity.

27. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the method further comprises not providing the pulsed electrical signal during at least the portion of the cardiac cycle of the patient.

28. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the detecting the portion of the cardiac cycle of the patient comprises acoustically detecting at least the portion of the cardiac cycle of the patient.

29. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the method further comprises:

detecting an inspiratory phase of a respiratory cycle of the patient;

wherein applying the pulsed electrical signal to the vagus nerve further comprises applying the pulsed electrical signal only during the inspiratory phase of the respiratory cycle of the patient.

30. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein at least one interpulse interval of the plurality of interpulse intervals is selectively varied from at least one other interpulse interval of the plurality of interpulse intervals.

31. The non-transitory computer readable program storage device encoded with instructions that, when executed by the computer, perform the method of claim 19, wherein the interpulse intervals of the pulsed electrical signal vary between each successive pulse of each microburst, and wherein the variation of the interpulse intervals between each successive pulse comprises one of an increase in the interpulse interval between each successive pulse and a decrease in the interpulse interval between each successive pulse.

32. An implantable medical device comprising one or more processors configured to implement a method to treat a brain disorder in a patient, the method comprising:

detecting a portion of a cardiac cycle of the patient;

applying to a predetermined location on a vagus nerve of the patient based on the detected portion of the cardiac cycle, a pulsed electrical signal configured to increase afferent activity on the vagus nerve which is conducted to the brain to treat the brain disorder, the pulsed electrical signal comprising a plurality microbursts, wherein each microburst other than a last of the plurality of microbursts is separated from an adjacent microburst by an interburst interval, and at least one interburst interval is varied from at least one other interburst interval, and wherein each microburst of the pulsed electrical signal includes:

from 2 to 5 pulses per microburst;

a plurality of interpulse intervals, each interpulse interval being between adjacent pulses of the microburst, each interpulse interval ranging from about 5 to about 10 milliseconds, wherein at least one interpulse interval of the plurality of interpulse intervals within the microburst is varied from at least one other interpulse interval of the plurality of interpulse intervals within the microburst; and

a microburst duration in a range of 4 to 40 milliseconds.

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33. The implantable medical device of claim **32**, wherein the plurality of interpulse intervals are varied from within a range.

34. The implantable medical device of claim **33**, wherein the range includes at least a first time period, a second time period, and a third time period.

35. The implantable medical device of claim **34**, wherein each time period is randomly selected within the range.

* * * * *

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摘要(译)

植入的电信号发生器向患者的迷走神经递送新的外源电信号。迷走神经将源自心脏和肺的动作电位传导到大脑的各种结构，从而在这些结构中引起迷走神经诱发电位。外源电信号模拟和/或增强源自患者心脏和/或肺的内源传入活动，从而增强脑的各种结构中的迷走神经诱发电位。外源电信号包括一系列电脉冲，这些电脉冲被组织或图案化成一系列微爆，每个微爆包括2到20个脉冲。在微爆流之间不发送脉冲。每个微爆流可以与ECG的QRS波部分同步。在各种脑结构中增强的迷走神经诱发电位可用于治疗各种医学病症，包括癫痫和抑郁症。

