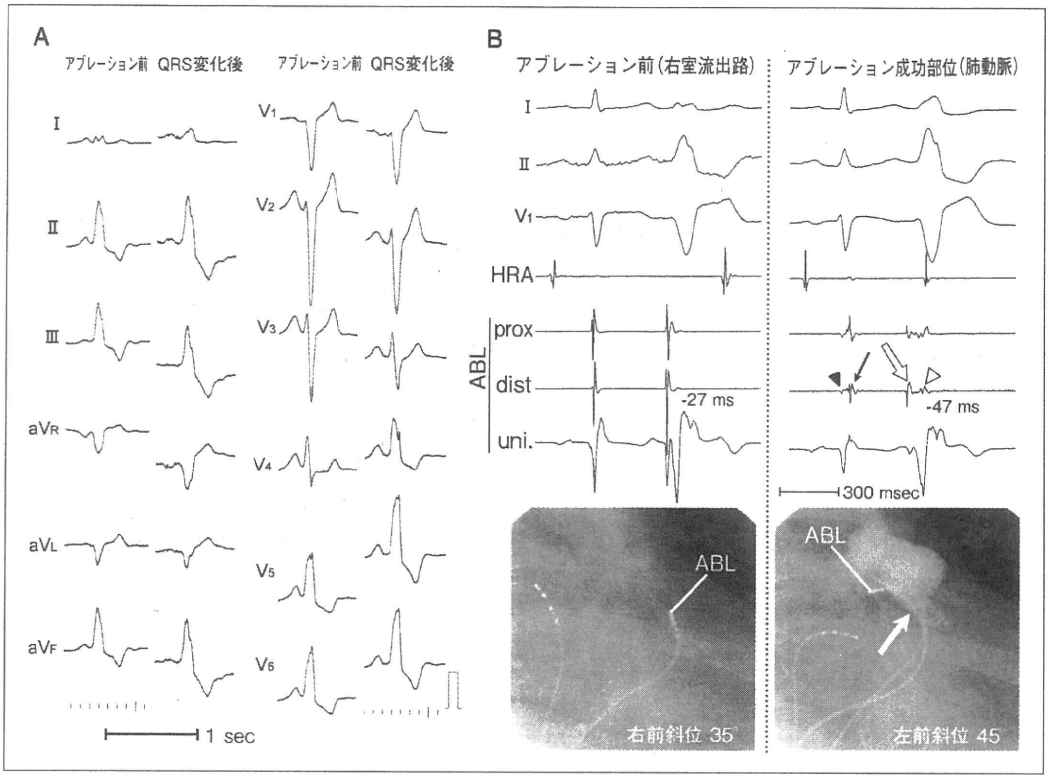

図2　肺動脈起源特発性心室期外収縮

A：12誘導心電図，B：アブレーション部位心内電位記録とカテーテル位置．心電図波形からは右室流出路起源が考えられ，アクチベーションマップにてQRS波形に27 msec先行する早期興奮部位を右室流出路のposterior attachment近傍に認めた．アブレーション後にQRS波形の変化を認めたが，期外収縮は消失せず，その後の右室流出路内でのアブレーションも不成功であった．肺動脈内をマッピングしたところ，洞調律時に比較的振幅の小さい鈍な電位(▼)とそれに続く鋭なスパイク電位(⬇)を，また，頻拍時にはQRSに47 msec先行するスパイク電位(⇩)とそれに続く鈍な電位(▽)を認めた．同部位に対するアブレーションにて根治した．

ABL：アブレーション用カテーテル，dist：遠位，HRA：高位右房，prox：近位，uni.：単極誘導記録．

〔文献8)より引用改変〕

て肺動脈起源頻拍に特徴的な心電図所見はないと考えたほうがよい[8]．本頻拍では肺動脈に進展した右室心室筋(遺残心筋)内に頻拍の起源があり，その興奮が肺動脈内の遺残心筋を伝導する[9]．遺残心筋を伝播した興奮の出口は主に右室流出路に存在することが多く，流出路内のその出口が心臓のなかで比較的低いところ，もしくは右室流出路の自由壁側であれば，下壁誘導のR波高は小さくなる．また，頻拍の出口が流出路内の複数箇所に存在するか，あるいは遺残心筋が扇状に広がって流出路に付着している場合には，右室流出路での通電中に頻拍の主な出口となる右室流出路の位置が移動するために頻拍のQRS波形が次々に変化し，かつそれに伴い右室流出路内の最早期興奮部位も移動するという所見を認める(図2)[8]．また，頻拍の出口となる肺動脈弁直下の右室流出路にてペーシングを行うと良好なペーシング波形が得られることが多い[8]．したがって，従来心電図波形から右室流出路起源と診断されていたようなQRS波形の異なった複数の頻拍を認める症例，あるいは右室流出路でのアブレーション中にQRS波

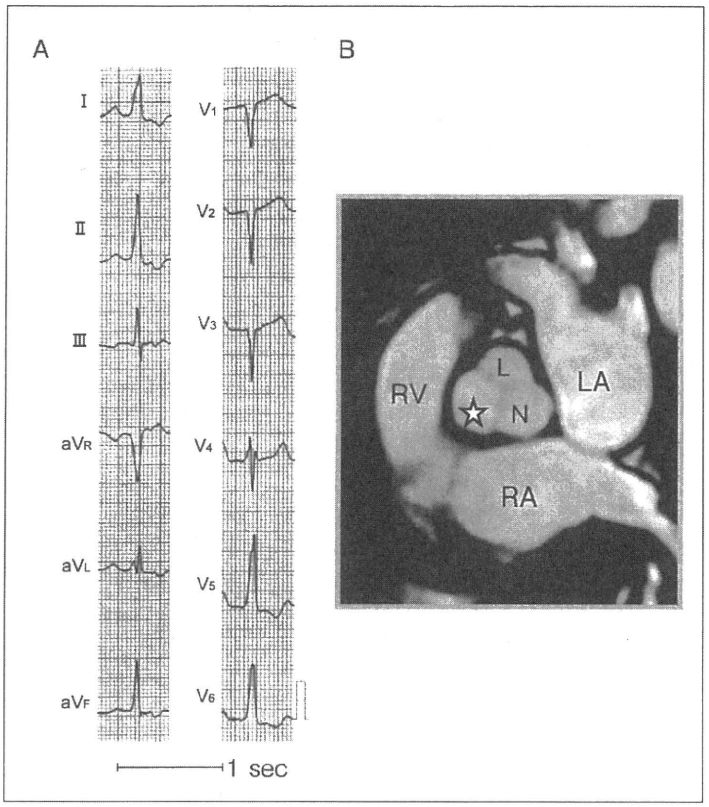

図3
右室流出路低位His束近傍起源心室期外収縮
A：12誘導心電図.
B：左室短軸MRI像(大動脈弁レベル)．右冠尖(星印)はHis束部に近接している.
L：左冠尖，L(R)A：左(右)房，N：無冠尖，RV：右室.

形が変化し，右室流出路内にて追加アブレーションを行っても根治できない症例中に肺動脈起源の頻拍が多く含まれていた可能性がある．このような症例を認めた場合には，肺動脈内を丹念にマッピングしてみることが大切である[8].

3．右室流出路低位のHis束近傍起源

左脚ブロック型，下方軸，Ⅰ誘導でR(RR')パターン(ほかの右室流出路起源頻拍に比してⅠ誘導のR波高は大きい)，その他V_1誘導にQ波を認める．aV_L誘導はRSR'，あるいはRR'パターンを呈することが多いが，QSパターンを呈することもある．また，高位の右室流出路頻拍に比べて，下壁誘導のR波高は全体に小さい傾向を示し，そのなかで特にⅢ誘導のR波高が小さいことが本頻拍の特徴である(図3A)[4), 10)]．解剖学的にHis束領域の後方は大動脈が接しており(図3B)，大動脈右冠尖，ときに無冠尖起源の頻拍の心電図波形は本頻拍に類似するため鑑別が必要である(後述).

Ⅲ．左室流出路起源

左室流出路起源の特発性心室頻拍はその起源により，左室心内膜起源と左室心外膜起源の二つに大別される(表1)[2)]．左室心内膜起源は，①大動脈弁直下の大動脈弁僧帽弁連続部起源と②上部基部中隔起源[11)]の二つに分類されるが，その頻度は前者が高い．大動脈弁僧帽弁連続部起源の頻拍には，左線維三角近傍起源(僧帽弁輪前内側・前外側起源)の僧帽弁輪部頻拍(後述)も含まれる[2), 12)]．一方，左室心外膜起源はそのアブレーション成功部位から，①大動脈冠尖(左冠尖，あるいは右冠尖)よりアブレーション可能な頻拍[6), 13)~15)]と②大動脈冠尖からのアブレーションが不可能な頻拍に分類される[2)]．大動脈左冠

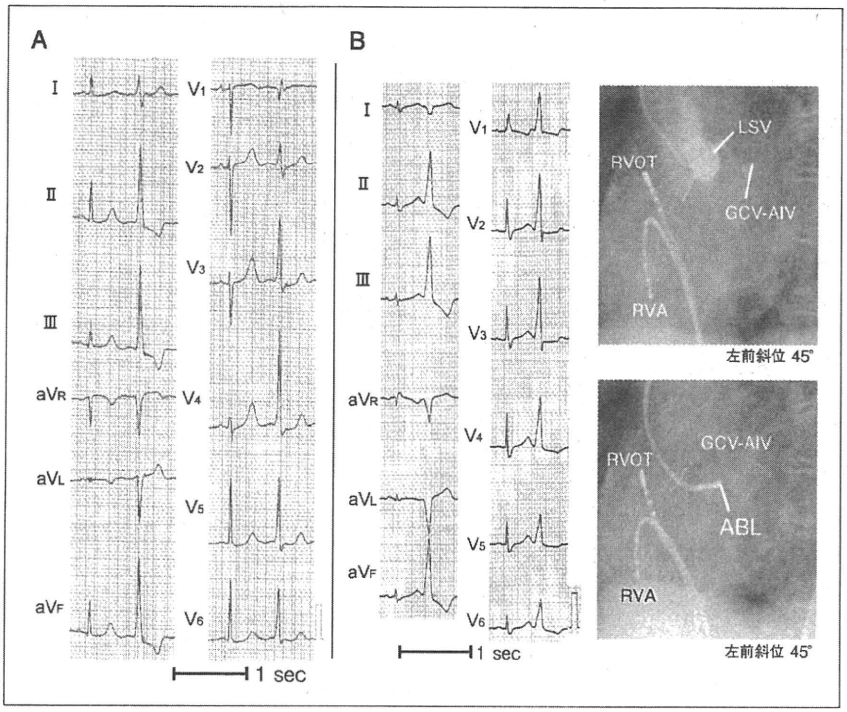

図4
左室流出路起源心室不整脈
A：大動脈弁直下の僧帽弁輪部前内側起源心室期外収縮．心電図上，V_6誘導にs波を認める．
B：大動脈弁直下起源心室期外収縮〔心電図(左)とアブレーション成功部位(右)〕Aと同様に左室心内膜側起源であるが，本例ではV_6誘導にs波は認めない．
ABL：アブレーションカテーテル，GCV-AIV：大心静脈－前室間静脈に留置した電極カテーテル，HRA：高位右房，LSV：左バルサルバ洞，RVA：右室心尖部，RVOT：右室流出路．
〔文献4)より引用改変〕

尖からのアブレーションが不可能(不成功)な頻拍は，冠尖より離れた部位の心外膜側心筋にその起源があると考えられ，その根治には冠静脈内，肺静脈，あるいは直接，心外膜側からのアブレーションが必要であり，近年その報告が散見される[16)~18)]．

1．心電図波形の特徴と右室流出路起源不整脈との鑑別

V_6誘導にs波(0.1 mV以上)を認める場合，左室心内膜側起源頻拍の可能性が高い(図4A)．逆に左冠尖起源，および左冠尖より離れた左室心外膜側起源の頻拍症例ではV_6誘導にs波は認めない．また，大動脈弁直下(僧帽弁輪部の前内側部)の左室心内膜側起源頻拍でもs波を認めないことが多い(図4B)[4)]．

右室起源と左室起源の頻拍の鑑別には，胸部誘導移行帯の位置，I誘導のQRS形態，そしてV_1，V_2誘導のR波の持続時間とR波とS波の振幅の比が参考となる．例えば，左室起源頻拍では右室起源頻拍に比べてI誘導にてS波を認める，また移行帯がV_4誘導以前に存在する場合が多い，などである(図5A)[4)]．V_1，V_2誘導で計算するR wave duration index(R波の幅/QRS幅；V_1，V_2誘導で計算し，大きい方の値を用いる)とR/S amplitude ratio(R波の振幅/S波の振幅：大きい方の値を用いる)は左冠尖起源心室頻拍の診断に有用で(図5B)，R wave duration indexが0.5以上，あるいはR/S amplitude ratioが0.3以上の場合には右室流出路起源頻拍よりも左冠尖からアブレーション可能な頻拍である可能性が高い(図6A)[13)]．ただし，いずれの指標にもoverlapを認めるため，これらの指標を参考にしつつも，全体的に考えることが大切である[13)]．

2．大動脈左冠尖よりアブレーション可能な心外膜起源頻拍

左室心外膜起源頻拍のなかでその起源が左冠尖に近い場合には，同部位からのアブレーションが可能である[6), 13)~15)]．一方，頻拍起源が左冠尖から比較的遠い所に存在する場合には，たとえ左冠尖内で最早期興奮部位が記録されてもアブレーションは不成功に終わる可能性が高い．左冠尖からのアブレーショ

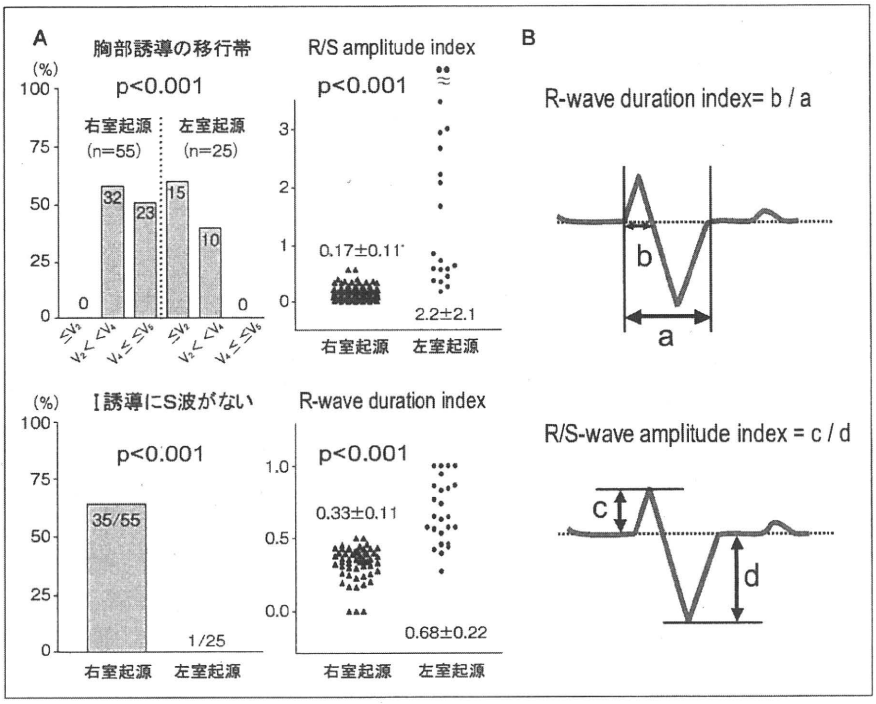

図5　左室流出路起源心室不整脈

A：右室流出路起源心室不整脈との鑑別〔文献4)より引用改変〕

B：R wave duration index，およびR/S amplitude ratioの算出法.

ン不能な頻拍は，左冠尖に比較的離れた大心静脈と前室間静脈の移行部近傍にその起源を有すると考えられている[6]．前述のR wave duration index，あるいはR/S amplitude ratioでは左冠尖からのアブレーションの可否は判定できない[4]．左冠尖からアブレーション不可能な頻拍の起源は，アブレーション可能な頻拍に比べて，より左方，あるいは下方にその起源が存在すると考えられており，aV_L誘導とaV_R誘導のQ波高の比およびV_1誘導のS波高が両者の鑑別に有用である．aV_L誘導とaV_R誘導のQ波の比(Q：aV_L/aV_R)が1.4以下，かつV_1誘導のS波高が1.2 mV未満の場合には左冠尖からアブレーションできる可能性が高い[4),18)]．流出路起源頻拍の起源同定のためにわれわれが作成した心電図波形を用いたアルゴリズムを図7に示す[4]．

QRS起始部がスラー状(デルタ波様)を呈する場合や，あるいは胸部誘導上のmaximum deflection index(=[胸部誘導中，QRS起始から最大振幅までの最短値/QRS幅]が0.55以上の場合(感度100％，特異度98.7％)，大動脈冠尖からアブレーション不可能な心外膜起源頻拍である可能性が高い[16]．また，下壁誘導のなかで最も大きいR波高を有する誘導のQRS起始から最大振幅までの時間(peak deflection index)が0.6を超える場合，頻拍の起源は心室中隔深部，あるいは心外膜側起源であり，心筋内カテーテルアブレーションが不成功となる可能性が高いことも報告されている[19]．

3．大動脈弁のほかの部位からアブレーション可能な頻拍

右冠尖起源の頻拍の心電図の特徴として，①左冠尖起源のものに比べて下壁誘導のR波高は小さく，II誘導のR波高がIII誘導のR波高に比べて大きいこと(II/III ratio＞1)，および②左脚ブロックパターンでV_2誘導ではやや幅の広い波高の小さなR波を認

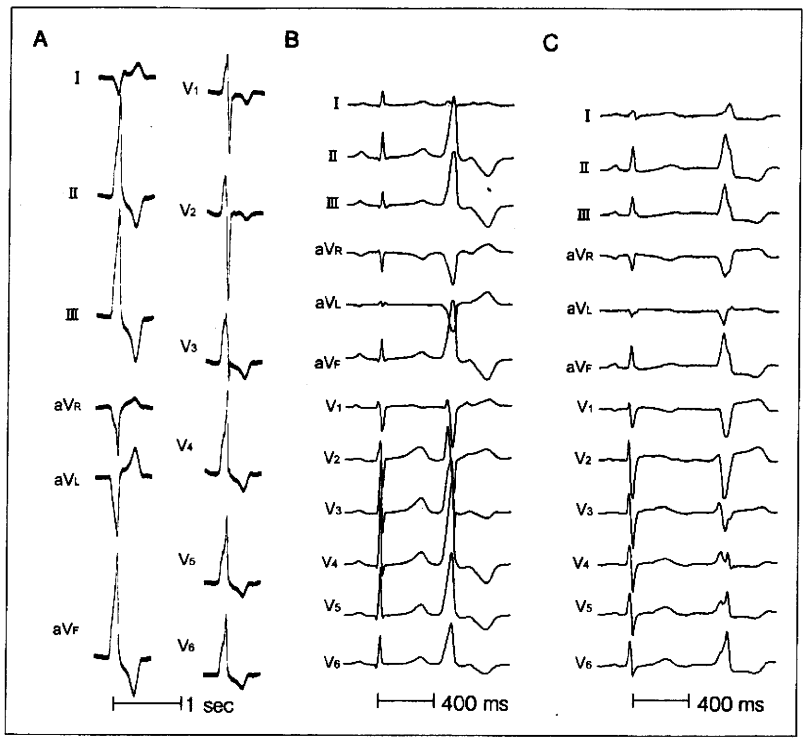

図6　大動脈冠尖，およびその近傍起源の特発性心室期外収縮

A：左冠尖起源．R wave duration indexは0.5以上，またR/S amplitude ratioも0.3以上である．

〔文献6)より引用改変〕

B：左右のバルサルバ洞接合部起源．

C：右冠尖起源.右室のHis束近傍起源頻拍に波形は類似．

める事例が多いことが報告されている(図6C)[21]．右冠尖は右室流出路のHis束近傍(上方)に近接しており(図3B)，右冠尖起源頻拍と右室流出路のHis束近傍起源頻拍は良く似た波形を呈する[21]．したがって，右室流出路のHis束近傍からのアブレーションが不可能な際には右冠尖，ときに無冠尖のマッピングを施行することが大切である．また，左右のいずれの冠尖からのアブレーションも不能であるが，左右のバルサルバ洞接合部でアブレーションが可能な頻拍も存在し(図6B)，V_1～V_3誘導でqrSパターンを認める事例が多いことなどが報告されている[22]．

頻拍起源が右冠尖から左右のバルサルバ洞接合部，さらには左冠尖に向かうにつれて，頻拍波形は，①Ⅰ誘導のQRS波形に陰性成分が出現する，②Ⅲ誘

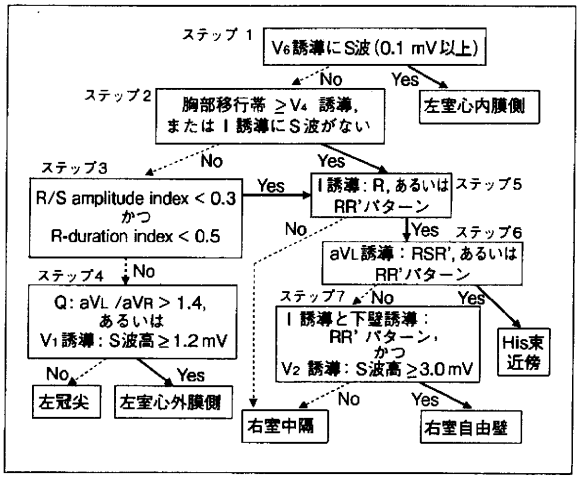

図7　流出路起源心室不整脈の局在診断のためのアルゴリズム

感度88%，特異度95%．

〔文献4)より引用改変〕

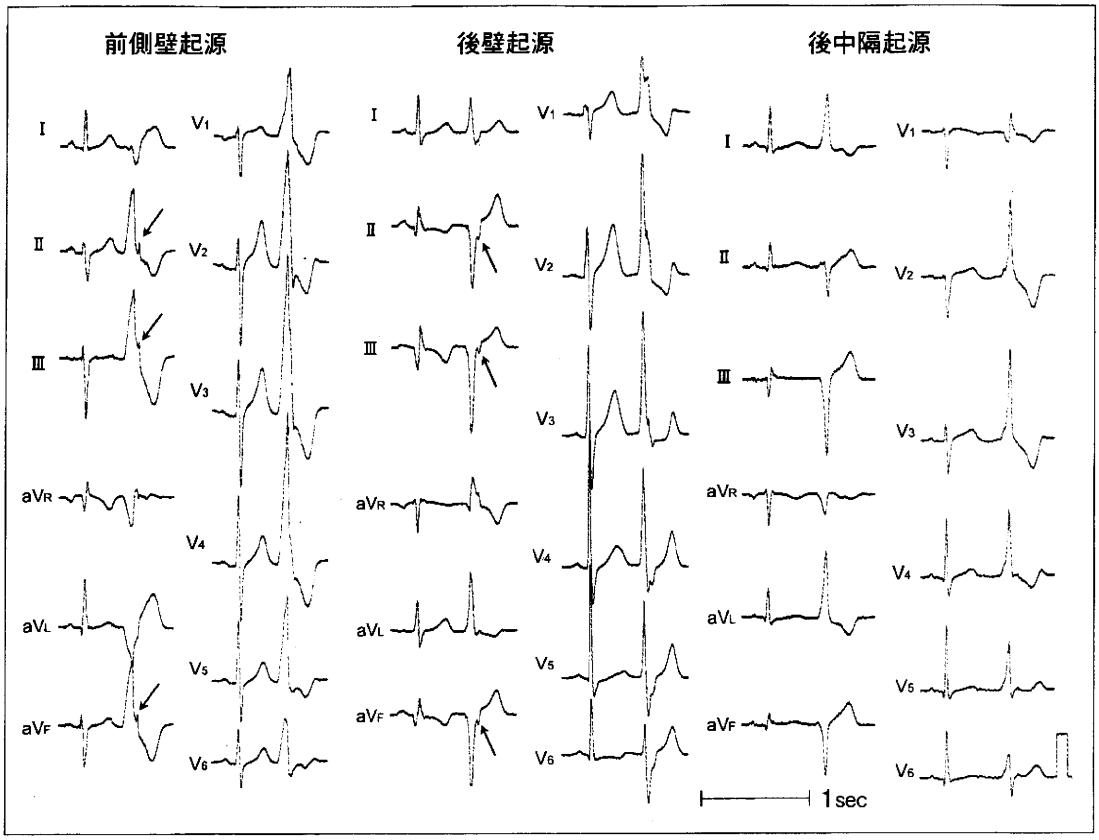

図8　僧帽弁輪起源心室性期外収縮

僧帽弁輪の前側壁，および後壁のいわゆる左室自由壁側起源のものでは下壁誘導にてQRS波形の後半部にノッチ(late notching：矢印)を認める．一方，後中隔起源のものでは，ノッチは認めずQRS幅も狭い．

〔文献12)より引用改変〕

導のR波高が増大，逆にII誘導とIII誘導のR波高比(RII/III)が低下する，そして胸部誘導の移行帯が反時計方向に向かうようになることがわかる(図6)．

IV．僧帽弁輪起源

特発性心室不整脈症例中の5%前後にみられる(表2)．僧帽弁輪前側壁—内側壁の左線維三角近傍起源の頻拍が最も多く，後中隔起源が続き，後壁，および側壁例も報告されている[12),23)]．このなかで左線維三角近傍起源の僧帽弁輪部前壁起源の頻拍は，心電図上は下方軸を呈し，流出路頻拍の範疇に入る[2)]．

本頻拍は左室心内膜側から起こる頻拍で右脚ブ

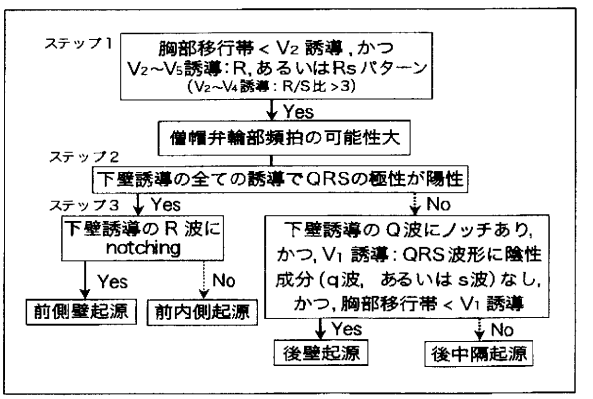

図9　僧帽弁輪起源心室不整脈の診断とその局在診断のためのアルゴリズム

〔文献12)より引用改変〕

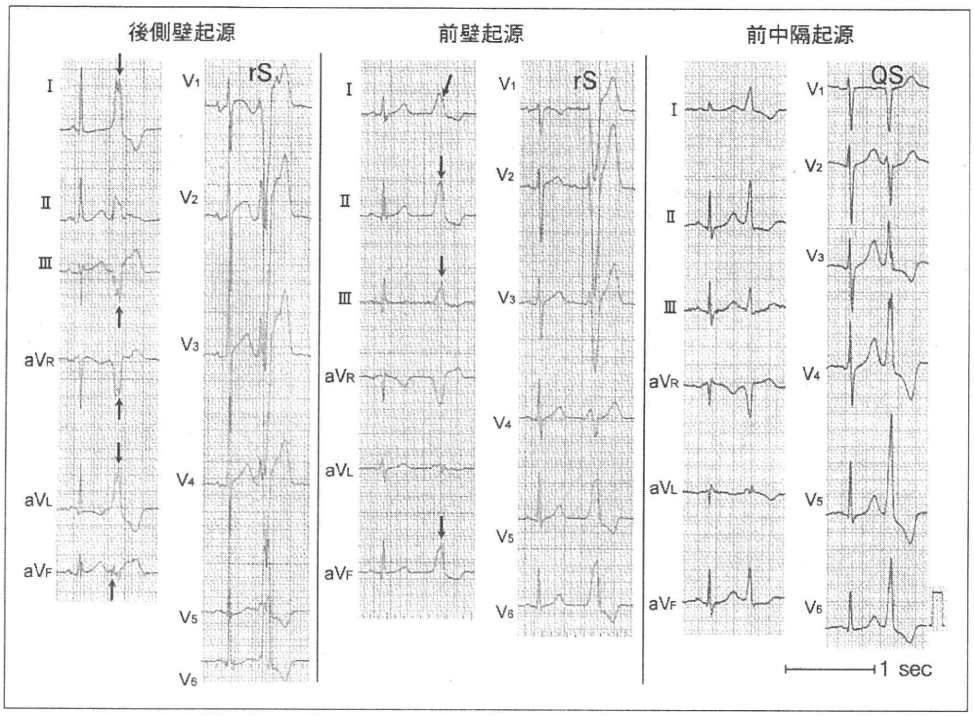

図10　三尖弁輪起源心室期外収縮

三尖弁輪の後側壁，および前壁のいわゆる右室自由壁側起源のものでは，QRS波形にノッチ(矢印)を認める．一方，前中隔起源のものでは，ノッチは認められずQRS幅も狭い．

〔文献24)より引用改変〕

ロック波形を呈し，V_5あるいはV_6誘導にs(S)波を認める(図8)．通常，胸部移行帯はV_1誘導よりも前(反時計方向)に認められる．後中隔起源のものではV_1～V_2誘導間に移行帯を認めることもあるが，V_2誘導より後(時計方向)に移行帯を認めることはない．V_2～V_5誘導はR，あるいはRsパターンを呈し，V_6誘導にもR(r)波を認める[12]．

僧帽弁輪中隔側(後中隔，および前内側部)に起源を有する場合，QRS幅は比較的狭く，逆に自由壁(前側壁，および後壁)に起源を有する場合にはQRS波形は広く，QRS波形の後半成分にノッチ(late notching)を認めることが多い(図8)．また，自由壁起源の不整脈では，中隔起源の不整脈と比べて，心室の興奮が左室から右室へと段階的に起こるためにQRS幅はより広くなり，ノッチは心内電位記録上，右室自由壁の興奮に一致する．また，下壁誘導のQRS波形の極性は起源の高さの指標となり，前側壁では全下壁誘導で陽性，逆に後壁，後中隔起源では陰性となる[12]．

僧帽弁前側壁は左側，かつ高位に位置するために，aV_L誘導のQRS極性は前側壁起源の場合には陰性，逆にやや右側，かつ低位に位置する後中隔，後壁起源の場合には陽性を呈する．後壁，および前側壁起源の場合，I誘導はRsパターン，V_1誘導はRパターンを呈する．一方，前内側(前中隔近傍)，および後中隔起源の場合にはI誘導はノッチのないRパターンを呈し，V_1誘導のQRS波形には陰性成分(qR, qr, rS, rs,あるいはQSパターン)を認めることが多い．また，III誘導とII誘導のQ波高比は後壁起源に比べて，後中隔起源で大きい傾向がある(図8)[12]．上記の所見をもとに作成した僧帽弁輪部起源頻拍の診断，ならびに局在診断のためのアルゴリズムを図9に示す．

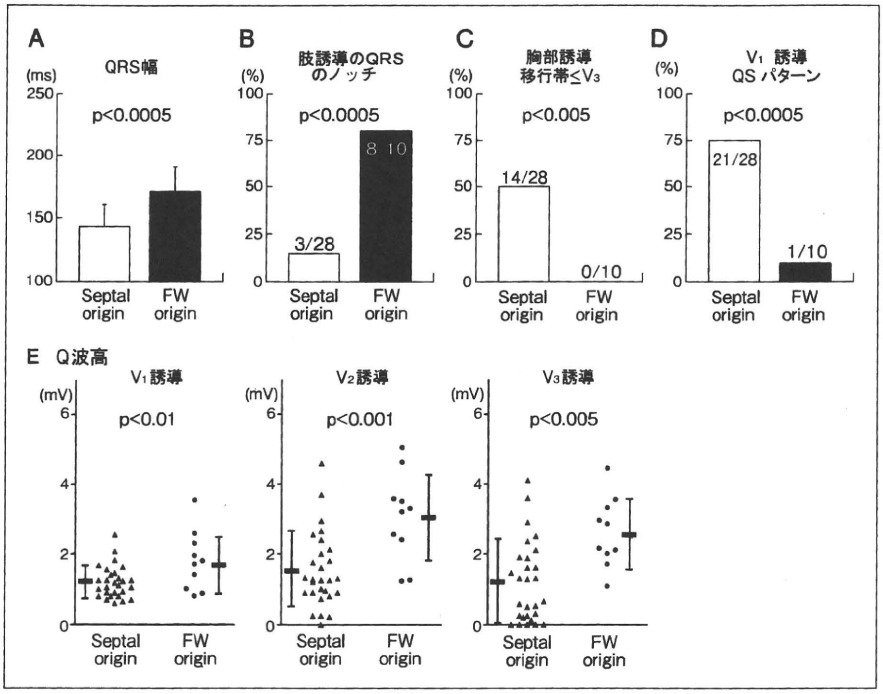

図11　三尖弁輪起源心室不整脈の自由壁起源と中隔起源の主な心電図学的指標の比較検討

〔文献24)より引用改変〕

V．三尖弁輪起源

特発性心室不整脈のおよそ8％を占める(表2)．三尖弁輪のいかなる部位からも起こりうるが，自験例では74％の症例が三尖弁輪中隔起源，残る26％が自由壁起源と，自由壁側に比べて中隔側，特に前中隔部にその発生頻度は高い(表2)．

心電図上，左脚ブロック波形，かつI誘導でR(r)パターンのQRS波形を呈する．そのうち95％とほとんどの症例でaV_R誘導のQRS波形に陰性成分(QS, qs, Qr, qrパターン)を認め，逆にaV_L誘導では95％の症例で陽性成分(r or R波)を認める(図10)[24]．自由壁起源の症例では中隔起源の症例に比べて，QRS幅は広く，またV_1～V_3誘導のQ波高は大きい．また，自由壁起源の症例では中隔起源の症例に比べて，QRS波形に明らかなノッチを認める症例が多く，逆に中隔起源の症例では自由壁起源の症例に比べV_1誘導でQSパターンを認める症例が多い．胸部誘導の移行帯は中隔起源頻拍では50％の症例でV_3誘導以前に認められるが，自由壁起源の症例ではV_3誘導以前に移行帯は認められない[24]．これらの自由壁起源と中隔起源心室不整脈の主な心電図学的指標の比較検討結果を図11に示す[24]．

Ⅵ．おわりに

12誘導心電図波形の解析から特発性心室不整脈の局在診断が可能である．アブレーション中に頻拍波形に変化を認め，その波形解析により心内の異なる部位からの頻拍が疑われるならば，ためらうことなくその部位のマッピングを行うことが根治のために必要である．左冠尖からアブレーション不能な心外膜側起源頻拍に対しては，イリゲーションカテーテルの使用，冠静脈洞からのアプローチ，あるいは心外膜直接アプローチの普及により，今後その成功率はさらに向上する可能性がある．

〔文　献〕

1) Badhwar N, Scheinman MM : Idiopathic ventricular tachycardia : Diagnosis and management. Curr Probl Cardiol ,2007 ; 32 : 7～43

2) Nogami A, Tada H : Idiopathic left ventricular tachycardia. Catheter Ablation of Cardiac Arrhythmia-Basic Concepts and Clinical Applications-, ed by Wilber D, Packer DL, Stevenson WG, Blackwell Publishing, Oxford, p298～313

3) Stevenson WG, Soejima K : Catheter ablation for ventricular tachycardia. Circulation, 2007 ; 115 : 2750～2760

4) Ito S, Tada H, Naito S, Kurosaki K, Ueda M, Hoshizaki H, Miyamori I, Oshima S, Taniguchi K, Nogami A : Development and validation of an ECG algorithm for identifying the optimal ablation site for idiopathic ventricular outflow tract tachycardia. J Cardiovasc Electrophysiol ,2003 ; 14 : 1280～1286

5) Tada H, Ito S, Naito S, Kurosaki K, Ueda M, Shinbo G, Hoshizaki H, Oshima S, Nogami A, Taniguchi K : Prevalence and electrocardiographic characteristics of idiopathic ventricular arrhythmia originating in the free wall of the right ventricular outflow tract. Circ J ,2004 ; 68 : 909～914

6) Tada H, Nogami A, Naito S, Fukazawa H, Horie Y, Kubota S, Okamoto Y, Hoshizaki H, Oshima S, Taniguchi K : Left ventricular epicardial outflow tract tachycardia : A new distinct subgroup of outflow tract tachycardia. Jpn Circ J, 2001 ; 65 : 723～730

7) Sekiguchi Y, Aonuma K, Takahashi A, Yamauchi Y, Hachiya H, Yokoyama Y, Iesaka Y, Isobe M : Electrocardiographic and electrophysiologic characteristics of ventricular tachycardia originating within the pulmonary artery. J Am Coll Cardiol, 2005 ; 45 : 887～895

8) Tada H, Tadokoro K, Miyaji K, Ito S, Kurosaki K, Kaseno K, Naito S, Nogami A, Oshima S, Taniguchi K : Idiopathic ventricular arrhythmias arising from the pulmonary artery : Prevalence, characteristics, and topography of the arrhythmia origin. Heart Rhythm, 2008 ; 5 : 419～426

9) Timmermans C, Rodriguez LM, Crijns HJ, Moorman AF, Wellens HJ : Idiopathic LBBB-shaped ventricular tachycardia may originate above the pulmonary valve. Circulation, 2003 ; 108 : 1960～1967

10) Yamauchi Y, Aonuma K, Takahashi A, Sekiguchi Y, Hachiya H, Yokoyama Y, Kumagai K, Nogami A, Iesaka Y, Isobe M : Electrocardiographic characteristics of repetitive monomorphic right ventricular tachycardia originating near the His-bundle. J Cardiovasc Electrophysiol, 2005 ; 16 : 1041～1048

11) Callans DJ, Menz V, Schwartzman D, Gottlieb CD, Marchlinski FE : Repetitive monomorphic tachycardia from the left ventricular outflow tract : Electrocardiographic patterns consistent with a left ventricular site of origin : J Am Coll Cardiol, 1997 ; 29 : 1023～1027

12) Tada H, Ito S, Naito S, Kurosaki K, Kubota S, Sugiyasu A, Tsuchiya T, Miyaji K, Yamada M, Kutsumi Y, Oshima S, Nogami A, Taniguchi K : Idiopathic ventricular arrhythmia arising from the mitral annulus : A distinct subgroup of idiopathic ventricular arrhythmias. J Am Coll Cardiol, 2005 ; 45 : 877～886

13) Ouyang F, Fotuhi P, Ho SY, Hebe J, Volkmer M, Goya M, Burns M, Antz M, Ernst S, Cappato R, Kuck KH : Repetitive monomorphic ventricular tachycardia originating from the aortic sinus cusp : Electrocardiographic characterization for guiding catheter ablation. J Am Coll Cardiol, 2002 ; 39 : 500～508

14) Kanagaratnam L, Tomassoni G, Schweikert R, Pavia S, Bash D, Beheiry S, Neibauer M, Saliba W, Chung M, Tchou P, Natale A : Ventricular tachycardias arising from the aortic sinus of valsalva : An under-recognized variant of left outflow tract ventricular tachycardia. J Am Coll Cardiol, 2001 ; 37 : 1408～1414

15) Hachiya H, Aonuma K, Yamauchi Y, Igawa M, Nogami A, Iesaka Y : How to diagnose, locate, and ablate coronary cusp ventricular tachycardia. J Cardiovasc Electrophysiol, 2002 ; 13 : 551～556

16) Daniels DV, Lu YY, Morton JB, Santucci PA, Akar JG, Green A, Wilber DJ : Idiopathic epicardial left ventricular tachycardia originating remote from the sinus of Valsalva : Electrophysiological characteristics, catheter ablation, and identification from the 12-lead electrocardiogram. Circulation, 2006 ; 113 : 1659～1666

17) Obel OA, d'Avila A, Neuzil P, Saad EB, Ruskin JN, Reddy VY : Ablation of left ventricular epicardial outflow tract tachycardia from the distal great cardiac vein. J Am Coll Cardiol, 2006 ; 48 : 1813～1817

18) Kaseno K, Tada H, Tanaka S, Goto K, Yokokawa M, Hiramatsu S, Naito S, Oshima S, Taniguchi K : Successful catheter ablation of left ventricular epicardial tachycardia originating from the great cardiac vein : a case report and review of the literature. Circ J, 2007 ; 71 : 1983～1988

19) Hachiya H, Hirao K, Sasaki T, Higuchi K, Hayashi T, Tanaka Y, Kawabata M, Isobe M : Novel ECG predictor of difficult cases of outflow tract ventricular tachycardia : peak deflection index on an inferior lead. Circ J, 2010 ; 74 : 256～261

20) Lin D, Ilkhanoff L, Gerstenfeld E, Dixit S, Beldner S,

Bala R, Garcia F, Callans D, Marchlinski FE : Twelve-lead electrocardiographic characteristics of the aortic cusp region guided by intracardiac echocardiography and electroanatomic mapping. Heart Rhythm, 2008 ; 5 : 663～669

21) Yamada T, McElderry HT, Doppalapudi H, Kay GN : Catheter ablation of ventricular arrhythmias originating in the vicinity of the His bundle : significance of mapping the aortic sinus cusp. Heart Rhythm, 2008 ; 5 : 37～42

22) Yamada T, Yoshida N, Murakami Y, Okada T, Muto M, Murohara T, McElderry HT, Kay GN : Electrocardiographic characteristics of ventricular arrhythmias originating from the junction of the left and right coronary sinuses of Valsalva in the aorta : the activation pattern as a rationale for the electrocardiographic characteristics. Heart Rhythm, 2008 ; 5 : 184～192

23) Kumagai K, Yamauchi Y, Takahashi A, Yokoyama Y, Sekiguchi Y, Watanabe J, Iesaka Y, Shirato K, Aonuma K : Idiopathic left ventricular tachycardia originating from the mitral annulus. J Cardiovasc Electrophysiol, 2005 ; 16 : 1029～1036

24) Tada H, Tadokoro K, Ito S, Naito S, Hashimoto T, Kaseno K, Miyaji K, Sugiyasu A, Tsuchiya T, Kutsumi Y, Nogami A, Oshima S, Taniguchi K : Idiopathic ventricular arrhythmias originating from the tricuspid annulus : Prevalence, ECG characteristics, and results of the radiofrequency catheter ablation. Heart Rhythm, 2007 ; 4 : 7～16

Classification and assessment of computerized diagnostic criteria for Brugada-type electrocardiograms

Mitsuhiro Nishizaki, MD,* Kaoru Sugi, MD,† Naomi Izumida, MD,‡ Shiro Kamakura, MD,§ Naohiko Aihara, MD,§ Kazutaka Aonuma, MD,‖ Hirotsugu Atarashi, MD,¶ Masahiko Takagi, MD,# Kiyoshi Nakazawa, MD,** Yasuhiro Yokoyama, MD,†† Mutsuo Kaneko, PhD,‡‡ Jiro Suto, PhD,§§ Tetsunori Saikawa, MD,‖‖ Noboru Okamoto, MD,¶¶ Satoshi Ogawa, MD,## Masayasu Hiraoka, MD,*** for the Investigators of the Japan Idiopathic Ventricular Fibrillation Study and the Subgroup of the Japanese Society of Electrocardiology

*From the *Department of Cardiology, Yokohama Minami Kyosai Hospital, Yokohama, †Division of Cardiovascular Medicine, Toho University Ohashi Medical Center, Tokyo, ‡Department of Pediatrics, Tokyo Medical and Dental University, Tokyo, §Department of Cardiovascular Medicine, National Cardiovascular Center, Suita, ‖Department of Internal Medicine, Cardiovascular Division, Institute of Clinical Medicine, University of Tsukuba, Tsukuba, ¶Nippon Medical School Tama Nagayama Hospital, Tokyo, #Department of Internal Medicine and Cardiology, Osaka City University Graduate School of Medicine, Osaka, **Division of Cardiology, Department of Internal Medicine, St. Marianna University School of Medicine, Kawasaki, ††Division of Cardiology, National Hospital Organization Disaster Medical Center, Tachikawa, ‡‡Fukuda Denshi Company Ltd, Tokyo, §§Nihon Kohden Corporation, Tokyo, ‖‖Departments of Internal Medicine and Laboratory Medicine, Faculty of Medicine, Oita University, Oita, ¶¶Aichi Sannomaru Hospital, Nagoya, ##Department of Cardiology, Keio University, Tokyo, ***Tokyo Medical and Dental University, Tokyo, Japan.*

BACKGROUND Although a Brugada-type electrocardiogram (ECG) is occasionally detected in mass health screening examinations in apparently healthy individuals, the automatic computerized diagnostic criteria for Brugada-type ECGs have not been established.

OBJECTIVE This study was performed to establish the criteria for the computerized diagnosis of Brugada-type ECGs and to evaluate their diagnostic accuracy.

METHODS We examined the ECG parameters in leads V1 to V3 in patients with Brugada syndrome and cases with right bundle branch block. Based on the above parameters, we classified the ECGs into 3 types of Brugada-type ECGs, and the conditions for defining each type were explored as the diagnostic criteria. The diagnostic effectiveness of the proposed criteria was assessed using 548 ECGs from 49 cases with Brugada-type ECGs and the recordings from 192,673 cases (36,674 adults and 155,999 school children) obtained from their annual health examinations.

RESULTS The Brugada-type ST-segment elevation in V1 to V3 was classified into 3 types, types 1, 2/3, and a suggestive Brugada ECG (type S). The automatic diagnostic criteria for each type were established by the J-point amplitude, ST-segment elevation with its amplitude and configuration, as well as the T-wave morphology in leads V1 to V3.

CONCLUSION The proposed criteria demonstrated a reasonable accuracy (type 1: 91.9%, type 2/3: 86.2%, type S: 76.2%) for diagnosing Brugada-type ECG in comparison to the macroscopic diagnosis by experienced observers. Moreover, the automatic criteria had a comparable detection rate (0.6% in adults, 0.16% in children) of Brugada-type ECGs to the macroscopic inspection in the health screening examinations.

KEYWORDS Brugada syndrome; J wave; ST-segment elevation; Coved-type ST-segment elevation; Saddleback-type ST-segment elevation; Computerized diagnosis; Health screening examination

ABBREVIATIONS ECG = electrocardiogram; **NPV** = negative predictive value; **PPV** = positive predictive value; **RBBB** = right bundle branch block; **SCD** = sudden cardiac death; **VF** = ventricular fibrillation; **VT** = ventricular tachycardia

(Heart Rhythm 2010;7:1660–1666)

Brugada syndrome is characterized by unique electrocardiographic (ECG) changes and carries a high risk for sudden cardiac death (SCD) due to ventricular fibrillation (VF) in patients without major structural heart disease.[1–8] The hallmark for diagnosing Brugada syndrome is ST-segment elevation in leads V1 to V3, but similar ECG changes are seen in various normal and abnormal conditions.[1–6]

Dr. Kaneko is employed by the Fukuda Denshi Company Ltd. Dr. Suto is employed by the Nihon Kohden Corporation. **Address reprint requests and correspondence:** Dr. Mitsuhiro Nishizaki, Department of Cardiology, Yokohama Minami Kyosai Hospital, 1-21-1 Mutsuura-Higashi, Kanazawaku, Yokohama, Kanagawa, 236-0037, Japan. E-mail address: nisizaki@yhb.att.ne.jp. (Received March 17, 2010; accepted June 28, 2010.)

1547-5271/$ -see front matter © 2010 Published by Elsevier Inc. on behalf of Heart Rhythm Society. doi:10.1016/j.hrthm.2010.06.035

The consensus reports by the subgroup of the Heart Rhythm Society and European Heart Rhythm Association have proposed the diagnostic ECG criteria for Brugada syndrome.[5,6] According to the consensus reports, there are 3 ECG patterns, type 1, type 2, and type 3. Type 1 is regarded as a diagnostic sign for Brugada syndrome, and a final diagnosis can be made when at least 1 of the following conditions are also present: documented VF and/or polymorphic ventricular tachycardia (VT), a family history of sudden cardiac death at <45 years old, coved-type ECGs in family members, induction of VT/VF with programmed electrical stimulation, syncope, or nocturnal agonal respiration.

Although the 3 types of ECG waveforms are occasionally detected in mass health screening examinations, which mostly utilize computerized ECG machines, there have been no detailed methods for quantitatively discriminating waveforms similar to Brugada syndrome. Another issue related to the difficulty in the ECG diagnosis is that VF or SCD has occasionally been observed in cases of Brugada syndrome with ECG patterns not included in the 3 types in the consensus report.[7–13,16] In this study we sought to establish computerized diagnostic criteria for the detection of the Brugada-type ECG. We further assessed the diagnostic accuracy of the proposed criteria for the differentiation of ECG patterns in patients with Brugada syndrome, or right bundle branch block (RBBB), and in apparently healthy adults and school children.

Methods

Data acquisition and analysis of the ECG waveforms

A 12-lead ECG was recorded in all individuals using conventional and commercially available computerized ECG machines at a paper speed of 25 mm/s. The ECG records were acquired simultaneously, at least 6 limb or precordial leads. All ECG parameters were automatically acquired and calculated during 2 cardiac cycles. The following definitions and data acquisition were used: The J point in leads V1 to V3 was defined as the timing of the J point in lead V5 with simultaneous recordings in V1 to V6. The J-wave amplitude was automatically measured as the height from the isoelectric line. The positive peak deflection after the R wave was defined as the STmax, the timing after 40 ms of the STmax as STmax40 and that after 80 ms as STmax80. The STmax was identical to the R′ (or r′) wave of RBBB in conventional ECG terminology. The minimum point of the ST-segment elevation and positive peak amplitude of the T wave were detected. Two morphologies of the ST-segment elevation, a coved type and a saddleback type, were other conditions for defining the diagnosis of a Brugada-type ECG.[3,4] Brugada-type ST-segment elevation was divided into type 1, type 2/3, and type S. Type 1 was defined as a coved-type ST-segment elevation with a J-point amplitude ≥0.2 mV and negative or flat T wave. This type was equivalent to type 1 of the consensus report.[5,6] Type 2/3 was defined as a saddleback-type ST-segment elevation with a J-wave amplitude ≥0.2 mV and positive or biphasic T waves, which would be included in type 2 and type 3 in the consensus report.[5,6] Type S, as abbreviated terminology for suggestive, was defined as a coved-type ST-segment elevation with J-wave amplitude ≥0.1 mV and <0.2 mV.

For a comparison to an automatic diagnosis, manual measurements in a macroscopic inspection were performed by 2 independent and experienced observers without any knowledge of the clinical background of the subjects.

The subjects included 32 patients with Brugada syndrome who were diagnosed according to the diagnostic criteria of the consensus report.[5,6] The ECGs from 118 cases with RBBB were diagnosed by macroscopic inspections from the stored records of previous health examinations in workers. The ECG data from the annual health examinations in 36,674 workers and 155,999 school children with ages between 8 and 18 years were used for an exploration of the diagnostic accuracy of the proposed criteria.

Diagnostic assessment of the proposed automatic criteria for a Brugada-type ECG

The conditions and waveforms for defining type 1, type 2/3, and type S ST-segment elevation were proposed and explored by their diagnostic accuracy to differentiate the ECG recordings in 57 leads (V1 to V3) displaying a coved-type ST-segment elevation from 32 patients with Brugada syndrome (Brugada group) and 151 leads displaying an rSR′ pattern (V1 to V3) in 118 cases with RBBB (RBBB group).

Then, 3 conditions for defining type 1, type 2/3, and type S were proposed as diagnostic criteria for a Brugada-type ECG, and their diagnostic effectiveness was assessed in 548 ECGs from 49 patients with a Brugada-type ECG by a macroscopic inspection. Type 1 ECG was classified when type 1 ST-segment elevation was observed in at least 1 of the 3 leads (V1 to V3). Type 2/3 ECG was defined when only type 2/3 or type 2/3 and type S ST-segment elevation was recorded in any of leads V1 to V3. Type S ECG was defined when type S ST-segment elevation alone was seen in any of leads V1 to V3.

We next examined the accuracy of how the proposed diagnostic criteria could differentiate Brugada-type ECGs using the recordings from 192,673 cases (36,674 workers and 155,999 school children) in their annual health examinations. The effectiveness of the automatic diagnosis was assessed in the ECGs retrieved from our cohorts by a macroscopic inspection.

Statistical analysis

The chi-square test was used to evaluate the differences in categorical variables between the 2 groups. A P value <.05 was considered significant.

Results

Classification and conditions of Brugada-type ECGs for the diagnostic criteria

There were 2 morphologies of the ST-segment elevation in leads V1 to V3, a coved type and a saddleback type, in

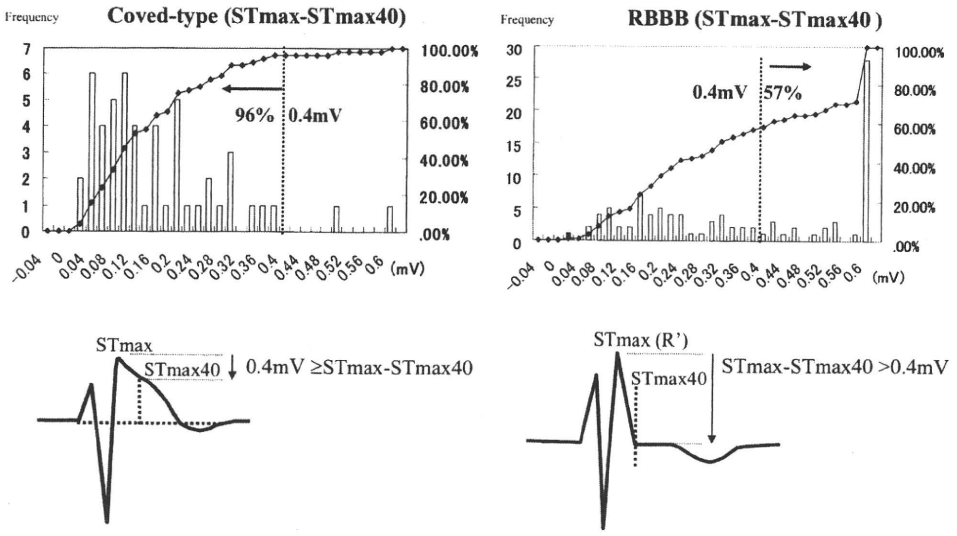

Figure 1 Distinction of a coved-type ST-segment elevation in Brugada syndrome (Brugada) and the ST-segment in right bundle branch block (RBBB). The histogram of the gradients between the amplitude of the STmax and STmax40 (STmax – STmax40) in 51 leads showing coved-type ST-segment elevation (Brugada group) is shown on the left and in 97 leads showing an rSR′ pattern with RBBB (RBBB group) on the right. See the detailed explanation in the text.

patients with Brugada syndrome and suspected cases.[3,4] We sought to establish the conditions for distinguishing the 2 morphologies of the ST-segment elevation with J-wave amplitude of ≥0.2 mV. In addition, we added a third condition of a coved-type ST-segment elevation and J-wave amplitude ≥0.1 mV and <0.2 mV, which was not included in the criteria by the consensus report,[5,6] but this type of ST-segment elevation might be seen in suspected cases of Brugada syndrome.[7–9] Based on the morphologies and amplitude of the ST-segment elevation, we classified the Brugada-type ECG into type 1, type 2/3, and type S. The ECG conditions for distinguishing the 3 types were further explored.

Type 1 ST-segment elevation

The ECG waveforms with a J-wave amplitude ≥0.2 mV and ST-segment elevation were automatically detected by the computerized ECG machines. For defining the coved-type ST-segment elevation, similar to the gradually descending ST-slope in the consensus report, we adopted the condition of STmax > STmax40 > STmax80 as the first step. Because coved-type ST-segment elevation with a J or STmax wave could be seen not only in patients with Brugada syndrome (Brugada group) but also in subjects with RBBB (RBBB group), we tested whether the combination of the 2 conditions (J wave amplitude ≥0.2 mV and STmax > STmax40 > STmax80) could discriminate the 2 groups. The combined conditions could be detected in 45 of 57 leads (V1 to V3) satisfying the condition from 32 patients in the Brugada group, which was macroscopically diagnosed by the 2 experienced observers. The same condition could also be detected in 2 (1.3%) of 151 leads (V1 to V3) with an rSR′ pattern from 118 cases in the RBBB group.

To improve the discrimination of the waveforms in the Brugada group from those in the RBBB group, the histograms of the gradient between the amplitude of the STmax and STmax40 in the 2 groups were explored (Figure 1). We adopted a condition of a voltage gradient within 0.4 mV between the amplitude of the STmax and STmax40 (0.4 mV ≥ STmax − STmax40) to discriminate between the 2 groups because this condition could detect the majority of patients (96%) in the Brugada group and 43% of those in the RBBB group ($P < .01$). Consequently, the 3 combined conditions (J-point amplitude ≥0.2 mV, STmax > STmax40 > STmax80, and 0.4 mV ≥ STmax − STmax40) could detect 97.8% of those (44 of 45 leads) in the Brugada group but only 1 (0.6%) of 151 leads in the RBBB group ($P < .01$). In addition, a negative or isoelectric T wave was adopted as the condition for defining type 1. Figure 2 shows an example of an ECG recording automatically diagnosed by the proposed criteria for type 1 using the above conditions.

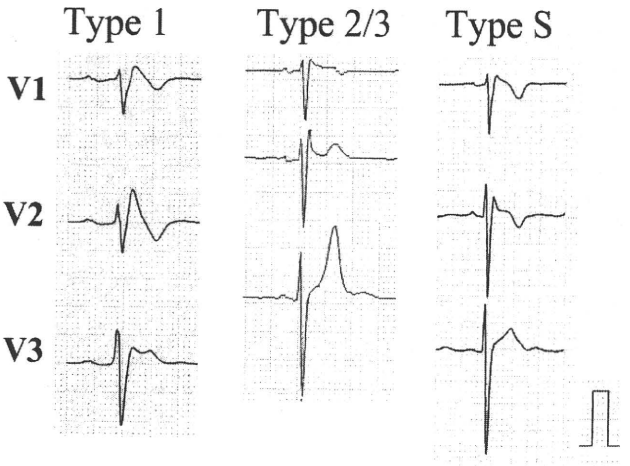

Figure 2 Electrocardiographic records of the 3 types diagnosed by the proposed criteria. **Left:** Type 1. **Middle:** Type 2/3. **Right:** Type S.

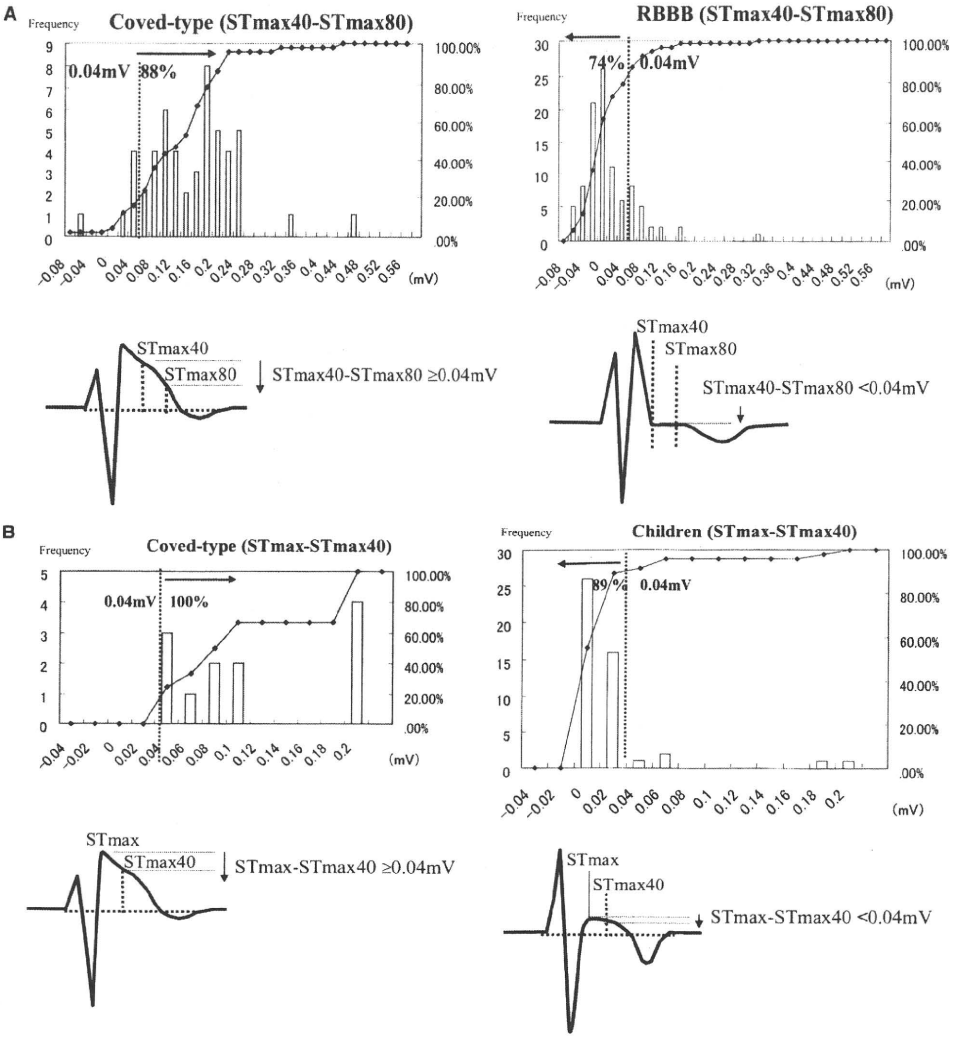

Figure 3 A histogram of the gradients between the amplitude of the STmax40 − STmax80 **(top)** and STmax − STmax40 **(bottom)** in the 2 groups (Brugada and RBBB groups). **Top:** Using the criteria of STmax40 − STmax80 ≥ 0.04 mV, the majority (88%) of the patients in the Brugada group were included, whereas 74% were excluded in the RBBB group. **Bottom:** Using an additional condition of STmax − STmax40 ≥ 0.04 mV, all of the leads in the Brugada group met the criteria and 42 of 47 electrocardiograms in RBBB children were excluded. Abbreviations as in Figure 1.

Type 2/3 ST-segment elevation

To define the saddleback-type ST-segment elevation, we adopted the conditions of the J-wave amplitude > the minimum point of the ST-segment (STmin), as well as the peak of the T wave (Tpeak) > STmin > 0 mV. The condition of the Tpeak > STmin > 0 mV could also define a positive or biphasic T wave. Thus, the conditions matching J-wave amplitude ≥0.2 mV, J amplitude > STmin, and Tpeak > STmin > 0 mV were determined as the criteria for type 2/3. Figure 2 represents an example of a type 2/3 ECG detected by this diagnostic criteria.

Type S ST-segment elevation

We adopted the parameter of J-wave amplitude ≥0.1 mV and < 0.2 mV, and other parameters similar to type 1 (STmax > STmax40 > STmax80, and 0.4 mV ≥ STmax − STmax40) for defining type S. The conditions combined by the above 3 parameters could be detected in 12 of 57 leads from 32 patients in the Brugada group and could also diagnose 6 of 151 leads with an rSR′ pattern in the RBBB group as type S. Therefore, we searched for other conditions to precisely differentiate the Brugada-type ECGs from those with RBBB. To this end, we applied a similar method as shown in Figure 1.

As for the STmax40 − STmax80 parameter, the histograms of the gradients between the amplitudes in the 2 groups are shown at the top in Figure 3. Applying the condition of an STmax40 − STmax80 ≥ 0.04 mV, the majority (88%) of the Brugada group patients were included, whereas 74% of the RBBB group were excluded ($P < .01$). Adding the condition of an STmax40 − STmax80 ≥ 0.04 mV to 0.4 mV ≥ STmax − STmax40, the remaining 2 leads in the RBBB group were still included, but the numbers of type S in the Brugada group remained unchanged ($P < .01$).

Another group to be differentiated from type S appeared to be that with incomplete RBBB and mild ST-segment

Type 1 : (coved-type ST-segment elevation)
① J point ≥0.2mV
② STmax >STmax40 >STmax80
③ T wave: under or on the isoelectric line
④ 0.4mV ≥STmax-STmax40

Type 2/3 : (saddleback-type ST-segment elevation)
① J point ≥0.2mV
② J point >STmin
③ Tpeak >STmin >0mV

Type S : (mild coved-type ST-segment elevation)
① 0.2mV >J point ≥0.1mV
②③: same criteria as Type 1
④ 0.4mV ≥STmax-STmax40 ≥0.04mV
⑤ STmax40-STmax80 ≥0.04mV

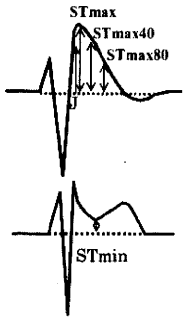

Figure 4 Classification and waveforms of Brugada-type electrocardiograms. See the detailed explanation in the text.

elevation in leads V1 to V3, often seen in healthy children. Therefore, we evaluated the reliability of the proposed conditions of STmax > STmax40 > STmax80, 0.4 mV ≥ STmax − STmax40 and STmax40 − STmax80 ≥ 0.04 mV in 47 leads showing mild ST-segment elevation in 37 children with incomplete RBBB. A close inspection of the ECG recordings with type S by a macroscopic diagnosis and those with incomplete RBBB suggested a difference in the steepness at the early portion of the ST-segment comparable to the STmax − STmax40 interval with a lesser degree in type S than in type 1. So, the parameter of the STmax − STmax40 was modified and the conditions with a new parameter were further evaluated by a similar method as shown in the case of type 1 (Figure 1). The histograms of the gradients between the amplitude of the STmax − STmax40 in 47 leads in the 37 ECGs from children were compared (Figure 3, bottom). The condition of STmax − STmax40 ≥ 0.04 mV could exclude 42 of 47 leads in the incomplete RBBB group. Three of the remaining 5 ECGs detected by this condition had the same recordings as type S by the macroscopic diagnosis. Therefore, we modified the conditions defining type S as J-wave amplitude ≥0.1 mV and <0.2 mV, STmax > STmax40 > STmax80, 0.4 mV ≥ STmax − STmax40 ≥ 0.04 mV, and STmax40 − STmax80 ≥ 0.04 mV. Consequently, the above conditions could exclude all 151 leads from the 118 ECGs with RBBB from type S, and detect type S in 12 of 57 leads from the Brugada group that agreed with the macroscopic diagnosis (Figure 3, bottom). An example of type S ECG detected by the automatic diagnostic criteria is shown in Figure 2. The automatic diagnostic criteria of type 1, type 2/3 and type S for Brugada-type ECGs are summarized in Figure 4.

Diagnostic accuracy of the automatic diagnostic criteria for Brugada-type ECGs

The recordings from 548 ECGs obtained in 49 cases with Brugada-type ECGs were diagnosed by the proposed criteria into type 1, type 2/3 and type S ECG. The results were compared with a macroscopic diagnosis by experienced observers (Table 1). Nearly 92% of the macroscopic diagnoses of type 1 ECGs by the experienced observers matched the automatic diagnosis (sensitivity 91.8%, specificity 96.8%, positive predictive value [PPV] 92.9%, negative predictive value [NPV] 96.3%). An additional 2.3% matched the automatic diagnosis of type 2/3 and type S ECGs, revealing 94.2% accuracy in total. The macroscopic diagnosis of a type 2/3 ECG had an 86.2% accuracy matched to the automatic diagnosis (sensitivity 86.2%, specificity 98.4%, PPV 99.0%, NPV 79.5%); 76.2% of type S ECG by the automatic diagnosis matched the macroscopic inspection (sensitivity 76.2%, specificity 99.4%, PPV 84.2%, NPV 99.0%).

The mass screening ECG recordings from 192,673 individuals undergoing annual health checkups for adult workers and school children were diagnosed into type 1, type 2/3 and type S ECGs by the proposed criteria (Table 1). The numbers detected by the automatic criteria for type 1, type 2/3 and type S ECGs were 20 (0.05%), 161 (0.44%), and 40 cases (0.11%), respectively, in the adult cases. Those in the children were 13 (0.008%), 154 (0.099%), and 89 cases (0.057%), respectively. The overall detection for the 3 types of Brugada ECGs was 221 cases (0.6%) in the adults and 256 (0.16%) in the children.

Table 1 Diagnostic accuracy using the proposed criteria for Brugada-type ECGs

	Brugada-type ECGs* 49 cases, n (%)			Random ECGs† 192,673 cases, n (%)	
	Macroscopic diagnosis			Adults	Children
Automatic diagnosis	Type 1 172 ECGs	Type 2/3 355 ECGs	Type S 21 ECGs	36,674 cases	155,999 cases
Type 1 ECG	158 (91.9)	11 (3.1)	1 (4.8)	20 (0.05)	13 (0.008)
Type 2/3 ECG	3 (1.7)	306 (86.2)	0 (0)	161 (0.44)	154 (0.099)
Type S ECG	1 (0.6)	2 (0.6)	16 (76.2)	40 (0.11)	89 (0.057)
Total	162 (94.2)	319 (89.9)	17 (81.0)	221 (0.6)	256 (0.16)

ECG = electrocardiogram.

*The automatic diagnosis using the proposed criteria was compared with the diagnosis made by experienced observers in a macroscopic inspection in a total of 548 ECGs from 49 cases with a Brugada-type ECG. The numbers in the columns are the automatically diagnosed numbers of cases and the percentage (%) relative to the macroscopic diagnosis.

†Incidence of a Brugada-type ECG diagnosed by the proposed criteria automatically in the mass screening examinations of 192,673 adults and school children.

We assessed the accuracy of the automatic diagnosis of ECGs retrieved from our cohorts by a comparison with the macroscopic inspection by the 2 experts. The experts reviewed 14 of 20 cases with type 1 ECGs by the automatic diagnosis, 146 of 161 with type 2/3, and 28 of 40 with type S in the adult cases. They diagnosed 10 of 13 cases with type 1, 144 of 154 with type 2/3, and 44 of 89 with type S in children.

Consequently, 78.5% (11 of 14 cases) of the automatic diagnoses of type 1 matched the macroscopic diagnosis by the 2 experts in adult cases (sensitivity 78.5%, specificity 98.8%, PPV 84.6%, NPV 98.2%). An additional 14.2% (2 of 14 cases) matched a macroscopic diagnosis of type 2/3 and type S, revealing a 92.8% accuracy in total. The automatic diagnosis of type 2/3 had a 95.2% (139 of 146 cases) agreement with the macroscopic diagnosis (sensitivity 95.2%, specificity 97.6%, PPV 99.2%, NPV 85.4%). Type S was 75% (21 of 28 cases) agreement with the macroscopic diagnosis (sensitivity 75.0%, specificity 98.7%, PPV 91.3%, NPV 95.7%). In children, 80% (8 of 10 cases) of the automatic diagnoses of type 1 matched the macroscopic diagnosis (sensitivity 80.0%, specificity 100%, PPV 100%, NPV 98.9%). An additional 10% (1 of 10 cases) matched the macroscopic diagnosis of type S, revealing 90% (9 of 10 cases) agreement in total. The automatic diagnosis of type 2/3 had 94.4% accuracy to the macroscopic diagnosis (sensitivity 94.4%, specificity 100%, PPV 100%, NPV 87.0%). Type S of the automatic diagnosis showed 77.2% agreement with the macroscopic diagnosis (sensitivity 77.2%, specificity 99.3%, PPV 97.1%, NPV 93.8%).

Discussion

In the present study, we established the automatic criteria for the computerized diagnosis of Brugada-type ECGs. The waveforms of the Brugada-type ECG were divided into 3 types, type 1, type 2/3, and type S. For the establishment of the diagnostic criteria, conditions for differentiating each type were determined and evaluated by comparing the ECG recordings from cases with Brugada syndrome and RBBB. Then, we examined the diagnostic usefulness of the criteria in a discrimination of 192,673 recordings of the ECGs from annual health checkups for workers and school children. The results yielded a reasonable rate of the recognition of Brugada-type ECGs in 0.6% of the adults and 0.16% of the children.

Although the 2 waveforms of the ST-segment elevation have been recognized in cases with Brugada syndrome,[3,4] the consensus report divided them into 3 types, type 1, type 2, and type 3.[5,6] Type 1 was assumed to be diagnostic of Brugada syndrome.[5,6] Although the initial report indicated persistent ST-segment elevation as a characteristic ECG finding of Brugada syndrome,[1] the fluctuating nature of the ST-segment elevation over time was recognized as a general feature of this syndrome.[3,4] The development of a spontaneous type 1 ECG was regarded as an important clinical sign for predicting cardiac events and the prognosis in patients with Brugada syndrome,[14] but other reports did not support this notion.[15,16] These findings may indicate that the detection of type 1 ECG as a diagnostic sign proposed by the consensus report may not always be applicable and can be missed in certain cases due to inconsistent appearance of a specific ST-segment elevation. Another diagnostic problem could emerge regarding the prognostic variables for Brugada syndrome with respect to the types of ST-segment elevation because the long-term prognosis of patients with Brugada syndrome in the non–type 1 group was similar to that in the type 1 group.[16] There was a missing form of ST-segment elevation among the 3 types in the consensus report: a coved-type ST-segment elevation with J-wave amplitude $\geq$0.1 mV and $<$0.2 mV. Therefore, we divided the Brugada-type ECGs into 3 types depending on morphologies of ST-segment elevation and J-wave amplitude. Type 1 had a coved-type ST-segment elevation with the J-wave amplitude $\geq$0.2 mV, which was equivalent to type 1 in the consensus report.[5,6] Type 2/3 had a saddleback-type ST-segment elevation with J-wave amplitude $\geq$0.2 mV. Type S represented a coved-type ST-segment elevation with J-wave amplitude $\geq$0.1 mV and $<$ 0.2 mV. We included type S because of the occasional association of an increased risk of VF or SCD in Japanese cases with Brugada syndrome.[7–9,11–13,16]

Automatic diagnostic criteria for the Brugada-type ECG

To define the waveforms of type 1, type 2/3, and type S, the conditions corresponding to each type were sought and formulated by the J-point amplitude, ST-segment elevation with amplitudes and morphology, as well as the T-wave morphology in leads V1 to V3 from the ECGs between the patients with Brugada syndrome and cases with RBBB. For defining the conditions of the coved-type and saddleback-type ST-segment elevation, the voltage amplitudes of the STmax, STmax40, and STmax80 as well as STmin, T-wave amplitude, and morphology were shown to be essential factors from the analysis of the ECGs in Brugada syndrome and RBBB cases, which shared a similarity in the ST-segment in leads V1 to V3. By choosing these parameters, each condition for defining the waveforms of type 1, type 2/3, and type S was shown a reasonable accuracy for diagnosing Brugada-type ECGs and the criteria for a computerized diagnosis were proposed.

Diagnostic accuracy of the proposed automatic criteria and prevalence of Brugada type ECGs in the mass screening examinations

The diagnostic accuracy of the proposed criteria was then evaluated in a large-scale mass screening of ECG recordings in workers and school children. The overall detection of a Brugada-type ECG was 0.6% in the adults and 0.16% in the school children. A Brugada-type ECG was reported to be detected with an incidence of 0.05% to 0.7% from the health screening examinations in Japan, which was mostly diagnosed by a macroscopic inspection.[7–9,11–13] Therefore,

the present results have a comparable diagnostic accuracy to those of the previous reports in Japan.

Among the 3 types of ECG criteria, type 2/3 was the highest frequency, followed by an order of type S and type 1 in both the adults and school children. The incidence of type S in the school children was nearly equivalent to that in the adults, which might reflect a prominent negativity of the T wave in V1 to V3 leads in this age group. This result may pose a need for special care in differentiating between Brugada syndrome and normal variants in children. These findings suggest that the automatic criteria were useful for detecting Brugada-type ECGs in the mass health screening examinations in adults and school children.

Study limitations

Although ST-segment elevation in V1 to V3 is an important sign of the Brugada phenotype, its presence is not necessarily diagnostic; the final diagnosis can be made through careful evaluation of various conditions including clinical symptoms, a family history, and other electrophysiological examinations. The present criteria for the automatic diagnosis, therefore, cannot be applied as a definite diagnosis for Brugada syndrome. Further, the clinical significance of the presentation of type 2/3 and type S has not been explored, except for cases in Japanese patients.[16] Therefore, the clinical significance of type 2/3 and type S must be further evaluated in Brugada patients of other ethnic groups.

For the diagnosis of Brugada syndrome, type 1 with drug provocation and higher lead placement were considered diagnostic.[5,6] Because the present study did not examine the ECG recordings during drug provocation tests or with a higher lead placement, our estimation of the diagnostic criteria might have missed those cases in which provocation would change a normal ECG into a type 1 ECG or those that would show a type 1 ECG with a higher lead placement.

Various drugs, including not only the ones used for the provocation tests but also those of different classes to be avoided by Brugada syndrome patients, were recommended because of occasional and unexpected developments of Brugada-type ST-segment elevation.[17] We could not obtain any information on these drug uses in our cohorts.

Although the diagnosis of RBBB is traditionally made in the presence of an S wave in the left precordial leads, we differentiated the Brugada-type ECG from RBBB by the J-point amplitude and the voltage amplitudes of the STmax, STmax40, and STmax80, as well as the T-wave morphology in the right precordial leads (V1 to 3). Therefore, RBBB may be more easily excluded from the Brugada-type ECGs by adding the condition of an S wave in the left precordial leads to these criteria.

Conclusion

The automatic diagnostic criteria for type 1, type 2/3, and type S were established to detect Brugada-type ECG in leads V1 to V3. The criteria could differentiate Brugada-type ECGs from those with RBBB. The 3 criteria had a comparable detection rate of Brugada-type ECGs to the macroscopic inspection by experienced observers in the health screening examinations in adults and school children.

Acknowledgement

The authors thank John Martin, IBHRE certified electrophysiology specialist, for reading the English manuscript.

References

1. Brugada P, Brugada J. Right bundle branch block, persistent ST-segment elevation and sudden cardiac death: a distinct clinical and electrocardiographic syndrome: a multicenter report. J Am Coll Cardiol 1992;20:1391–1396.
2. Brugada J, Brugada R, Brugada P. Right bundle-branch block and ST-segment elevation in leads V1 through V3. A marker for sudden death in patients without demonstrable structural heart disease. Circulation 1998;97:457–460.
3. Alings M, Wilde AAM. Brugada syndrome: clinical data and suggested pathophysiological mechanism. Circulation 1999;99:666–673.
4. Gussak I, Antzelevitch C, Bjerregaard P, et al. The Brugada syndrome: clinical, electrophysiologic and genetic aspects. J Am Coll Cardiol 1999;33:5–15.
5. Wilde AA, Antzelevitch C, Borggrefe M, et al. Proposed diagnostic criteria for the Brugada syndrome: consensus report. Circulation 2002;106:2514–2519.
6. Antzelevitch C, Brugada P, Borggrefe M, et al. Brugada syndrome: report of the second consensus conference. Circulation 2005;111:659–670.
7. Atarashi H, Ogawa S, Harumi K, et al. Three-year follow-up of patients with right bundle branch block and ST segment elevation in the right precordial leads: Japanese Registry of Brugada Syndrome. J Am Coll Cardiol 2001;37:1916–1920.
8. Matsuo K, Akahoshi M, Nakashima E, et al. The prevalence, incidence and prognostic value of the Brugada-type electrocardiogram: a population-based study of four decades. J Am Coll Cardiol 2001;38:765–770.
9. Miyasaka Y, Tsuji H, Yamada K, et al. Prevalence and mortality of the Brugada-type electrocardiogram in one city in Japan. J Am Coll Cardiol 2001;38:771–774.
10. Aihara N, Kamakura S, Kurita T, et al. Clinical profiles and prognosis of patients with symptomatic and asymptomatic Brugada syndrome from a multi-center study in Japan. Circulation 2005;17 Suppl II:3274.
11. Furushima M, Uno K, Tsuchihashi K, et al. Prevalence of asymptomatic ST segment elevation in right precordial leads with right bundle branch block (Brugada-type ST shift) among the general Japanese population. Heart 2001; 86:161–166.
12. Yamakawa Y, Ishikawa T, Uchino K, et al. Prevalence of right bundle-branch block and right precordial ST-segment elevation (Brugada-type electrocardiogram) in Japanese children. Circ J 2004;68:275–279.
13. Oe H, Takagi M, Tanaka A, et al. Prevalence and clinical course of the juveniles with Brugada-type ECG in Japanese population. Pacing Clin Electrophysiol 2005;28:549–554.
14. Priori SG, Napolitano C, Gasparini M, et al. Natural history of Brugada syndrome: insights for risk stratification and management. Circulation 2002;105: 1342–1347.
15. Takagi M, Yokoyama Y, Aonuma K, et al. Clinical characteristics and risk stratification in symptomatic and asymptomatic patients with Brugada syndrome: multicenter study in Japan. J Cardiovasc Electrophysiol 2007;18:1244–1251.
16. Kamakura S, Ohe T, Nakazawa K, et al. Long-term prognosis of probands with Brugada-pattern ST-segment elevation in leads V1-V3. Circ Arrhythm Electrophysiol 2009;2:495–503.
17. Postema PG, Wolpert C, Amin AS, et al. Drug and Brugada syndrome patients: review of the literature, recommendations, and an up-to-date website (www.brugadadrugds.org). Heart Rhythm 2009;6:1335–1341.