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Original Article

Age-Related Changes in the Anatomy of the Triangle of Koch: Implications for Catheter Ablation of Atrioventricular Nodal Re-entry Tachycardia

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ABSTRACT

Background: Atrioventricular nodal re-entrant tachycardia is the most common type of paroxysmal supraventricular tachycardia. We sought to assess whether important anatomic factors, such as the location of the slow pathway, proximity to the bundle of His, and coronary sinus ostium dimensions, varied with patient age, and whether these factors had an impact on procedural duration, acute success, and complications.

Methods: Baseline demographic and procedural data were collected, and the maps were analyzed. Linear regression models were performed to evaluate the associations between age and these anatomic variations. Associations were also assessed, with age categorized as being ≥ 60 years or < 60 years.

Results: The slow pathway was more commonly located in a superior location relative to the coronary sinus ostium in older patients. The location of the slow pathway moved in a superior direction by 1 mm for every increase in 2 years from the mean estimate of age. Additionally the slow pathway tended to be closer to the coronary sinus ostium in older patients, and the diameter of the ostium was larger in older patients. This resulted in longer procedure time, longer ablation times, and a greater need for long sheaths for stability.

RÉSUMÉ

Contexte : La tachycardie par réentrée nodale auriculoventriculaire est le type le plus fréquent de tachycardie supraventriculaire paroxystique. Nous avons voulu évaluer si des facteurs anatomiques importants, tels que l'emplacement de la voie lente, la proximité du faisceau de His et les dimensions de l'orifice du sinus coronaire (ostium), variaient avec l'âge, et si ces facteurs avaient un effet sur la durée de l'intervention, le succès à court terme et les complications.

Méthodologie : Des données sur les caractéristiques démographiques initiales et l'intervention ont été recueillies, et les cartes obtenues ont été analysées. Des modèles de régression linéaire ont servi à déterminer les corrélations entre l'âge et ces variations anatomiques. Les corrélations ont aussi été évaluées selon des catégories d'âge, soit ≥ 60 ans et < 60 ans.

Résultats : La voie lente a été repérée plus souvent dans un emplacement supérieur par rapport à l'orifice du sinus coronaire chez les patients plus âgés. L'emplacement de la voie lente s'était déplacé de 1 mm vers le haut pour chaque augmentation de 2 ans de l'estimation moyenne de l'âge. Par ailleurs, chez les patients plus âgés, la voie lente était généralement plus proche de l'orifice du sinus coronaire et le diamètre de l'orifice était élargi. Ces variations se sont traduites par une augmentation du temps d'intervention et d'ablation et par un besoin accru de longues gaines pour la stabilité.

Atrioventricular nodal re-entrant tachycardia (AVNRT) is the most common type of paroxysmal supraventricular tachycardia (SVT). Although the mean age of presentation is 32 years, there is a significant age range in which individuals with this arrhythmia may undergo catheter ablation.[1] The electrical substrate for AVNRT involves dual atrioventricular (AV) nodal physiology in which antegrade conduction of a premature atrial complex occurs along the slow pathway (SP), with retrograde conduction along the fast pathway, which may then initiate a typical (slow-fast) AVNRT or antegrade conduction along the fast pathway, with retrograde conduction along the slow pathway initiating an atypical (fast-slow) AVNRT. For both types of AVNRT, catheter ablation is used to target the SP, which is generally located in the lower one-third of the triangle of Koch in the posteroseptal region anterior to the ostium of the coronary sinus (CS).

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Ethics Statement: Approval was gained from the Regional Ethics Board, Sunnybrook Health Institution, Toronto, Ontario, Canada. All patients consented to all procedures being performed.

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Conclusions: The location of the slow pathway becomes more superior and closer to the coronary sinus ostium with increasing age. Additionally, the coronary sinus diameter increases with age. These factors result in longer ablation and procedural times in older patients.

Conclusions : L'emplacement de la voie lente devient plus éloigné vers le haut et plus proche de l'orifice du sinus coronaire avec le vieillissement. De plus, le diamètre du sinus coronaire augmente avec l'âge. Ces facteurs entraînent des temps d'ablation et d'intervention plus longs chez les patients plus âgés.

Given the very high success rates (approximately 98%) for catheter ablation in AVNRT, this procedure is considered the treatment of choice. During this procedure, the SP is targeted, using either radiofrequency energy or cryoablation, with the aim of rendering the tachycardia non-inducible at the end of the procedure. In general, this procedure is performed within the inferior mid-segment of the triangle of Koch; however, there may be variability in the anatomy of this region, which may result in mapping difficulty and less stability of the catheter. The objective of this study was to examine whether there are anatomic variations in this region that are more common with increasing age, and whether these have an impact on the technical complexity of the procedure, the equipment required, and the risk of complications.

Methods

All patients who underwent catheter ablation for ANVRT between January 2015 and August 2020 were included in this retrospective study. Approval was gained from the Regional Ethics Board, Sunnybrook Health Institution, Toronto, Ontario, Canada. All patients consented to all procedures being performed.

Electroanatomic mapping was performed using the Ensite cardiac mapping system (Abbott Technologies, St Paul, MN). All anti-arrhythmic drugs were held for at least 5 half-lives prior to the procedure. A 4-mm non-irrigated catheter (Flexability or Tacticath, Minneapolis) was used to collect anatomic data around the triangle of Koch, including the SP, the CS ostium, and the bundle of His. Respiratory compensation was performed for all cases.

The diagnosis of AVNRT was established either by the initiation of a narrow complex tachycardia with concentric activation and a His-to-atrial interval of < 60 msec in the case of a typical AVNRT, and ≥ 60 ms in atypical AVNRT in which entrainment from the right ventricular apex resulted in a post pacing interval minus tachycardia cycle length of > 110 ms. In the absence of inducible tachycardia, the presence of an AH jump with an echo beat in the presence of electrocardiography evidence of a narrow complex tachycardia consistent with AVNRT were felt to represent reasonable features suggestive of this tachycardia.

The SP was defined as a region anterior to the CS with an AV ratio of < 1 where catheter ablation resulted in junctional beats. The largest diameter of the CS was measured as the maximum distance from the superior rim of the CS ostium to the inferior rim or from the anterior rim to the posterior rim (whichever was the largest).

The bundle of His was recorded on the distal electrogram, and the distance was recorded from the location of ablation and the most inferior portion of the bundle of His. In the event of cases in which there were multiple ablation lesions, the lesion that resulted in junctional beats with no further inducible tachycardia, or no evidence of a jump and an echo beat where the tachycardia was non-inducible, was recorded as the location of the SP from where the distance to the bundle of His was recorded.

Baseline demographic and procedural data were collected, and the electroanatomic maps were analyzed. Ablation of the SP was performed by mapping the posterior aspect of the tricuspid annulus anterior to the CS, starting inferior and moving superior until there were junctional beats associated with ablation or until the procedure was terminated. A local atrial-to-ventricular signal ratio < 1.0 was required prior to the delivery of ablation. Power settings ranged from 35-55 W, with a temperature setting of 55°C. Ablation was not performed if the SP was within 4 mm of the most inferior aspect of the bundle of His.

The parameters that were measured are shown in Figure 1. The SP location was determined as the location where junctional beats occurred in the setting of radiofrequency, or where the final ablation was delivered in cases in which junctional beats did not occur. The distance from the SP to the most inferior aspect of the bundle of His was recorded. The CS ostium was demarcated, and the maximum diameter was recorded. The distance from the SP to the ostium of the CS

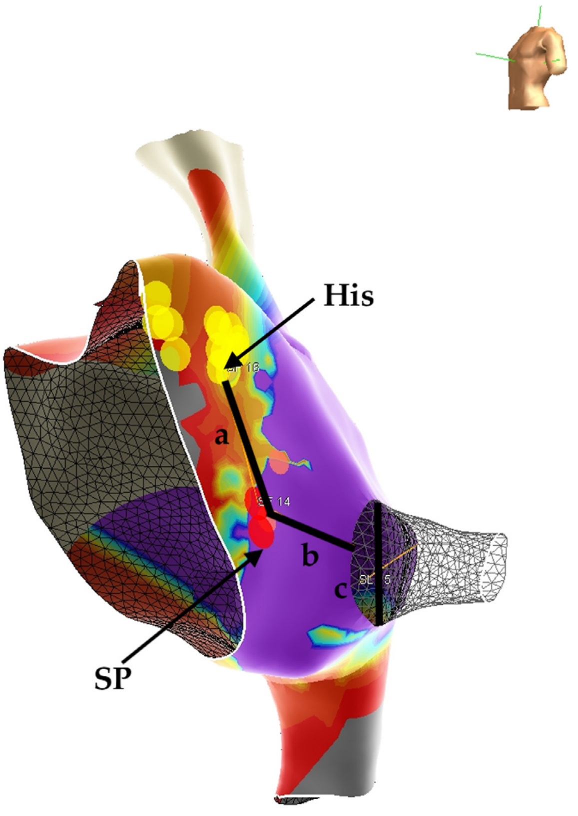

Figure 1. Electroanatomic map of the septum of the right atrium showing the locations of the bundle of His (**yellow**), the slow pathway (SP in **red**), the coronary sinus (CS), and the measurements made between these anatomic locations, including (**a**) the distance from the SP to the bundle of His, (**b**) the distance from the SP to to the CS ostium, and (**c**) the maximum diameter of the CS ostium.

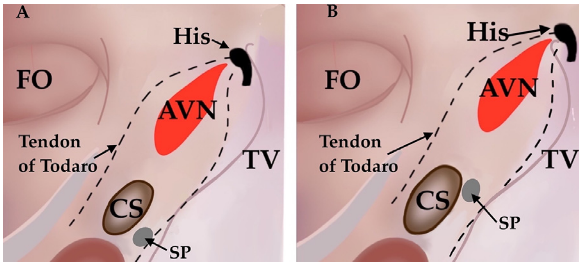

Figure 2. Comparison of the location of the slow pathway (SP) relative to the coronary sinus (CS), as well as the size relative to the diameter of the CS ostium and the location of the SP relative to the bundle of His. The SP becomes more superior and closer to the CS ostium with increasing age (**B** compared with **A**). The CS ostium is also larger in older patients, whereas the distance from the SP to the bundle of His is not significantly different. AVN, atrioventricular node; FO, fossa ovalis; TV, tricuspid valve.

was measured. The SP location was recorded as superior, middle, or inferior, relative to the location of the CS.

Statistical analysis

Linear regression models were performed in order to evaluate the associations between age and anatomic variations, including the location of the SP location, the distance from the SP to the bundle of His, diameter of the CS ostium, and distance of the SP to the CS ostium. An F test was applied to assess the overall significance of variables with more than 2 categories.

Associations were also assessed with age categorized as being ≥ 60 years or < 60 years. Linear regression models were used for continuous variables (SP distance to bundle of His, diameter of CS ostium, and distance of the SP to the CS ostium). Logistic regression models were fitted for categorical variables (inferior, middle, and superior location of the SP).

Results

Baseline characteristics

The baseline characteristics of 126 study patients are summarized in Table 1. The overall mean age was 51.7 (± 19.27) years, and 67% were male. Of all patients who underwent catheter ablation, 10 of 126 (8%) had a history of hypertension, 6 of 124 (5%) had diabetes mellitus, 4 of 124 (3%) had atrial fibrillation, and 4 of 124 (3%) had coronary artery disease. Although hypertension was more common in those who were aged ≥ 60 years (8 of 50 aged ≥ 60 years vs 2 of 76 for those aged < 60 years, $P = 0.02$), there was no significant difference in the incidence of diabetes mellitus, atrial fibrillation, or coronary artery disease between the groups. All patients had a history of palpitations, with 94 of 126 (74%) having documentation of tachycardia prior to the procedure.

Electrophysiology and procedural characteristics

The location of the bundle of His, the SP, and the CS ostium were mapped using the Ensite mapping system (Abbott Technologies). All patients received minimal sedation with benzodiazepine, as well as analgesia with fentanyl. No patients received general anesthesia.

All patients had either an AH or VA jump during atrial or ventricular stimulation, respectively, with at least one echo beat or inducible AVNRT confirmed by the activation sequence on the CS catheter and entrainment from the right ventricular apex. The effective refractory period of the AV node was 280 ± 50 ms (AV nodal effective refractory period 260 ± 40 ms for those aged < 60 years; AV nodal effective refractory period 280 ± 60 ms for those aged ≥ 60 years; $P = 0.08$), with an AV Wenckebach point of 320 ± 40 ms (AV Wenckebach point 300 ± 40 ms for those aged < 60 years; AV Wenckebach point 340 ± 40 ms for those aged ≥ 60 years; $P = 0.32$) There was no significant difference in these baseline parameters between those who were aged ≥ 60 years vs those who were aged < 60 years. In those in whom tachycardia was induced (86of 126 [68%] patients) the mean tachycardia cycle length was 340 ± 60 ms (310 ± 50 ms for those aged < 60 years vs 380 ± 40 ms for those aged ≥ 60 years; $P < 0.01$).

The mean procedural time was 95 ± 40 minutes (87 ± 32 minutes for those aged < 60 years vs 101 ± 42 minutes for those aged ≥ 60 years; $P = 0.02$). Mean radiofrequency time to achieve success (or until the end of the procedure) was 246 ± 54 seconds (194 ± 60 seconds for those aged < 60 years vs 310 ± 56 seconds; $P < 0.01$).

Table 1. Baseline characteristics and anatomic data for patients undergoing catheter ablation for atrioventricular nodal re-entrant tachycardia, categorized by age (< 60 or ≥ 60 years).

Characteristic/anatomic data	Patients aged < 60 y (n = 76)	Patients aged ≥ 60 y (n = 50)	Overall patients (N = 126)	*P*
Age, y	39.3 (±14.1)	70.5 (±6.5)	51.7 (19.3)	0.002
Gender, male	52 (68)	33 (66)	85	ns
Hypertension	2 (3)	8 (16)	10 (8)	0.02
Diabetes mellitus	2 (3)	4 (8)	6 (5)	0.04
Atrial fibrillation	0 (0)	4 (8)	4 (3)	0.01
Coronary artery disease	1 (2)	3 (6)	4 (3)	0.03
Weight, kg	77.8 (±20.1)	76.3 (± 16.9)	77.2 (± 18.9)	ns
Inferior	32 (42)	14 (28)	46 (37)	< 0.001
Middle	30 (39)	12 (24)	42 (33)	0.02
Superior	14 (19)	24 (52)	38 (30)	0.001
Slow pathway to bundle of His, mm	15.5 (± 6.12)	15.3 (±6.6)	15.4 (± 6.3)	ns
Diameter of CS ostium, mm	14.9 (± 3.8)	19.5 (±2.9)	16.8 (± 4.2)	0.001
Distance of SP to CS ostium (mm)	11.7 (± 5.2)	6.9 (±4.8)	9.8 (± 5.6)	0.001

Data are expressed as mean (± SD) or number (%), unless otherwise indicated.
CS, coronary sinus; ns, nonsignificant; SP, slow pathway.

Successful catheter ablation defined by the presence of junctional beats during catheter ablation with no more than an AH jump and an echo beat at the end of the procedure was achieved in 118 of 126 (94%) patients. The use of a sheath was required in 14 of 124 (11%) cases (2 of 124 (2%) in those aged < 60 years and 12 of 124 (10%) in those aged ≥ 60 years (P < 0.01). Of the sheaths used, 4 of 14 were non-deflectable, and 10 of 14 were deflectable sheaths. Non-irrigated 4-mm non-contact force catheters with either a medium curve (32 of 124 [26%]) or a large curve (92 of 124 [74%]) were used in all cases. There were no cases of AV block, significant PR interval prolongation, tamponade, or vascular complications in any patients.

Anatomic relationships

The mean distance from the SP to the bundle of His was 15.5 mm (± 6.2 mm). The mean diameter of the CS ostium and the mean distance of the SP to the CS ostium were 14.9 mm (± 3.8) and 11.7 mm (± 5.2), respectively. The proportions of patients with an inferior, middle, and superior SP location relative to the CS were 46 of 126 (37%), 42 of 126 (33%), and 38 of 126 (30%), respectively. There were 76 participants aged < 60 years, and 50 patients aged ≥ 60 years.

The SP was more commonly successfully ablated in a superior location relative to the CS ostium in older patients (age ≥ 60 years). In cases in which the SP was in a more superior location, the mean age was 14.3 years greater than that for any other locations combined. The location of the SP moved in a superior direction by 1mm for every increase in 2 years from the mean estimate of age. In those aged ≥ 60 years, a superior location of the SP was more common, compared with other locations, vs that in those who were aged < 60 years (log odds ratio = −1.6071, P < 0.001). Likewise, inferior locations were more common in those aged < 60 years when compared with those aged ≥ 60 years (log odds ratio = 2.3228, P < 0.001).

There was no significant relationship between age and the distance of the SP to the bundle of His (P = 0.20). The distance from the SP to the CS ostium was less for older patients compared with that for younger patients, with an effect of 1.37 between age and the distance to the CS (P < 0.001). The mean distance from the SP to the CS ostium was 11.7 mm (±5.2) in those aged < 60 years, and 6.9 mm (± 4.8) in those aged ≥ 60 years (P < 0.001). There was a positive correlation between age and the diameter of the CS ostium. The mean estimate of diameter of the CS ostium in individuals aged < 60 years decreased by 4.6 compared to that in those aged ≥ 60 years (P < 0.001).

Overall, the relationship between age and the distance from the SP to the bundle of His, the location relative to the coronary sinus, and the diameter of the coronary sinus were related to age, and a multivariate logistic regression analysis demonstrated that other confounding variables were not responsible for this relationship.

Discussion

The triangle of Koch is an important anatomic structure, which is critical in the catheter ablation of AVNRT. It is bounded by the tendon of Todaro posteriorly, the septal component of the septal leaflet of the tricuspid valve anteriorly, and the CS ostium inferiorly. The SP is located in the vestibular portion anterior to the CS ostium.[2]

Given the proximity of the SP to the compact AV node and the bundle of His, anatomic variations in this region are fundamental for the cardiac electrophysiologist. This is the first study to demonstrate age-related anatomic changes in the triangle of Koch in patients undergoing catheter ablation for AVNRT. Of note, there was a higher representation of women in this study than in most ablation studies. The main findings were that the site of successful SP ablation was more superior and closer to the CS ostium in older patients compared with younger patients, and that the CS ostium is larger. Additionally, there was no significant association between age and distance to the bundle of His, implying that this migrates more superiorly with age. Although there was no significant difference in success rates, which are generally high for this procedure, or complication rates, which are overall low, the mean duration of radiofrequency energy required to achieve success was long, as was the procedural time. The need for use of a sheath to maintain catheter stability was also more common in older patients.

A prior study using fluoroscopy only to measure the location of the SP also demonstrated a more superior location associated with increasing age.[2] This study is limited by a lack of electroanatomic mapping, so measurements may not be as accurate, and CS measurements were not available. Significant variability in the location of the SP and the anatomy of the triangle of Koch has been demonstrated using electroanatomic mapping and anatomic studies, although this is not related to increasing age.[3-5] The exact anatomic reasons for the changes found in this study are unknown. It has been suggested that hypertensive changes may be responsible[2]; there was a very low incidence of hypertension in our study, which makes this possibility less likely. It has been suggested that as the ascending aorta enlarges with age, this may displace the triangle of Koch and therefore alter the locations of the structures relative to the CS ostium.[6]

The clinical implications of these findings were demonstrated by longer procedural and ablation times, as well as an increased need to use long sheaths for stability. Sheaths are generally used to create stability of the ablation catheter, particularly when the site of ablation of the SP is close to a larger CS ostium. This information is useful for the planning of these procedures and the technique used to map the location of the SP. Despite this, there was no difference in complication rates, specifically the risk of AV block. These findings are consistent with rates found in recent cohort studies on acute and long-term procedural outcomes for radiofrequency ablation of typical AVNRT.[7]

Limitations

This is a nonrandomized retrospective study, and therefore, there are inherent biases that cannot be accounted for. It should be noted that the location of the SP and attempted location of successful SP ablation was defined based on the presence of junctional beats during catheter ablation, and in successful procedures, on the lack of inducibility of tachycardia or the absence of an echo beat where tachycardia could not be induced. It is possible that in the absence of a documented SP pathway potential, with increasing age and possible changes in fiber orientation, the location of the SP may not be exactly where the site of successful ablation occurred.

Lastly, in the case of a non-inducible tachycardia for which entrainment was not possible, a patient may have an atrial tachycardia or a paraseptal accessory pathway with the coincidental presence of dual AV nodal physiology, and catheter ablation in this region may have resulted in the successful modification of another arrhythmogenic focus.

Conclusions

The location of the SP becomes more superior and closer to the CS ostium with increasing age. Additionally, the CS diameter increases with age. All of these factors combined result in a longer procedure and ablation time, with an increased need for the additional use of long sheaths to maintain catheter stability. This increase had no impact on procedural success or the risk of complications.

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Disclosures

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