Our technique defines the maximum safe injection flow rate for any type of ventriculography catheter rather than leaving this to the clinician to decide on a case by case basis. Arbitrarily selecting a contrast flow rate does not guarantee lack of clinical or subclinical ventricular trauma. In addition, with the use of higher quality image intensification systems, flow rates for angiography can be quantitatively reduced into safe flow ranges without sacrificing film quality.

References
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Appendix
The Angiographic Jet Theory

Necessary key parameters for the mathematical solution were the mean blood pressure of the vascular chamber into which the angiographic injection was made, the diameter of the end hole of the catheter, the viscosity of the injectate, which was assumed to be the average between the viscosity of blood and that of the Renograin at body temperature, and the mean velocity of the injectate at the catheter exit hole. Because modern pump injection systems compensate for the length of the angiographic catheter, this parameter was not incorporated into our theory. Our theoretic computations, detailed elsewhere, revealed that all angiographic jets emanating from the end hole of a catheter, with or without side holes, have a jet Reynolds number greater than 77, and therefore are always turbulent. Turbulent jets were always present at injection flow rates used for ventricular, aortic, and even coronary arterial injections. Jet penetration distance was shown to be a function of the ratio of the initial total kinetic energy to the intravascular pressure, and, importantly, this relationship was shown to be independent of the jet Reynolds number. Thus, once the maximum energy available to the jet and the intravascular pressure were known, the jet penetration distance could be calculated in a straightforward fashion.

Coronary Sinus Pacing
Clinical Follow-up

PAUL GREENBERG, M.D., MARK CASTELLANET, M.D., JOHN MESSENGER, M.D., AND MYRVIN H. ELLESTAD, M.D.

SUMMARY Coronary sinus pacing is a safe and effective means of pacing from the atrium. In 66 patients with an average follow-up of 14 months, there was a 14% failure rate. There were transient problems in 14% which were subsequently corrected. There was a 6% death rate which was not pacemaker related. Successful atrial pacing with thresholds up to 6.0 mA is feasible. Atrial pacing was successful in 18 of 19 patients with varying degrees of atrioventricular block. Our experience with a new electrode has been very satisfactory.

INDICATIONS FOR AND THERAPEUTIC USES of atrial pacing have rapidly expanded in recent years.1-4 Successful long-term atrial pacing from the coronary sinus has been reported in a large series by Moss et al.1-4 Atrial pacing has been shown in several studies to be hemodynamically superior to ventricular pacing.5-10 Improvement in ventricular performance has been demonstrated consistently in a damaged ventricle when atrial pacing is compared to ventricular pacing.9-10 However, difficulties with pacing leads and lead positioning have hampered the widespread use of atrial pacing.1-4, 6-12

This article presents our experience and long-term follow-up with coronary sinus pacing.

Methods
A retrospective study was done reviewing the clinical records on all patients who had a permanent coronary sinus pacemaker inserted from 1970-1976. A total of 71 hospital charts and pacemaker records were reviewed for indications of pacemaker insertion, type of pacemaker, type of pacemaker lead, thresholds, ECG, atrial pacing studies, early complications, pacemaker failures and causes of death. Complete records and follow-up could be obtained on 66 patients. Of the five excluded cases, three patients were lost...
to follow-up and one patient had a transeptal puncture lead for atrial pacing inserted. One patient had a normally functioning coronary sinus pacemaker but his records were incomplete.

Permanent pacemakers were inserted using either a Medtronic bipolar or Cordis unipolar lead developed especially for the coronary sinus by the manufacturers at the request of our department. These leads have been modified from the standard lead to accommodate the anatomy of the coronary sinus by adding a flexible tip that extends beyond the electrode and prevents dislodgement when the pacer is retracted by respiratory motion (fig. 1). Of the 66 patients, 56 had the new modified leads and 10 the standard Cordis or Medtronic lead. The respiratory motion noted at implant in the initial patients led to the development of this new electrode since three of the initial 10 had catheter dislodgement. The lead was placed pervenously into the coronary sinus as previously described.\textsuperscript{3,4} The length of the coronary sinus was explored for the area of lowest threshold and the lead was positioned at this point which often tended to be near the coronary ostium. The Medtronic demand 5963, 5942, 5950 and the Cordis Omnistanicor demand 162 pacemakers were utilized.

The patients were followed up at the Long Beach Memorial Pacemaker Follow-up Clinic at regular one to three month intervals. The records were reviewed for pacer spike-R interval, magnetic pacer rate, waveform, presence of atrial capture, sensing, and evidence of A-V block.

Prior to the placement of a permanent pacemaker, an atrial pacing study was performed. The patients were paced from the coronary sinus beginning at a rate of 90 and increasing by increments of 10 to a maximum of 150 to evaluate for the presence of possible A-V block.

The patients were grouped into five categories on the basis of clinical indications for pacing. Group 1 consisted of four patients with uncontrolled ventricular tachycardia despite maximal in-hospital management with oral antiarrhythmics. Group 2 consisted of three patients with bradycardia and secondary ventricular escape beats and rhythms. Group 3 included eight patients with bradycardia and resultant symptomatic low cardiac output and congestive heart failure. Group 4 was comprised of 24 patients with bradycardia-tachycardia syndrome. Group 5 included 27 patients with symptomatic bradycardia without evidence of congestive heart failure or ventricular arrhythmias.

Results

Of 66 patients who met the criteria for inclusion in the study, there were 37 males and 29 females, ranging in age from 46 to 87 years with the average being 68. One patient had a functioning coronary sinus pacer for eight years which was first implanted in 1968. However, since the patient had moved and complete records were not available, he was not included in the study. The follow-up period ranged from 0–75 months with an average of 14 months and a median of 12 months. Patients with no follow-up months had early pacemaker failure. A failure constituted removal of the pacemaker lead due to dislodgement with inability to replace the lead in the coronary sinus, threshold rise that could not be corrected with repositioning, and progression of A-V block (fig. 2). There were a total of nine failures (14%).

The threshold at insertion ranged from 0.7 to 6.0 mA with a mean of 2.3 mA. There were four deaths (6%), all of which were nonpacer related. The pacer spike-R interval at insertion ranged from 0.12 to 0.24 sec with a mean of 0.17 sec. The follow-up pacer spike-R intervals ranged from 0.14 to 0.40 sec with a mean of 0.18 sec.

![Diagram of the heart and its venous system demonstrating the special coronary sinus lead in the coronary sinus.](http://circ.ahajournals.org/)

**Figure 1.** Top) Diagram of the heart and its venous system demonstrating the special coronary sinus lead in the coronary sinus. Middle) Medtronic bipolar coronary sinus catheter. Note the flexible tip extending beyond the distal electrode. Bottom) Cordis unipolar electrode with flexible distal tip.
Transient Problems

A transient problem was one which required repositioning the lead in the coronary sinus or increasing the pacemaker current with resultant successful atrial pacing. Seven of the nine problems occurred within the first 48 hours of insertion of the pacemaker. Three patients had a threshold rise manifested by a loss of capture. This was corrected by reprogramming the pacemaker from medium to high current output. Four patients required repositioning of the lead because of lead movement with resultant failure to capture. The two late problems occurred one and two months after pacemaker insertion and consisted of one threshold rise and one repositioning of the lead. The threshold for this group ranged from 1.2 to 5.0 mA with two of the patients having thresholds above 3.0. The one patient who had both an early and late problem had a threshold of 1.2 mA and had no further problems after 18 months of follow-up. The average threshold was 2.6 mA which did not differ significantly from the overall average of 2.3 mA.

Minor Problems

There were two categories of minor problems which did not require repositioning or removal of the coronary sinus lead. These included failure to sense and atrial fibrillation. Seven patients (10%) had sensing problems. Two failed to sense PVCs, three failed to sense PACs and three failed to sense both spontaneous sinus atrial and ventricular electrical activity. Of the five patients who had failure to sense atrial activity, none had an increased incidence of supraventricular tachycardia after paced insertion. Four of these patients had a history of recurrent atrial tachycardia and two of the four had no recurrence after the pacemaker was implanted. One had a marked reduction in the frequency of attacks and one showed no change. The fifth patient had no history of tachycardia before or after paced insertion.

There were three patients who had normal pacemaker function of both sensing and pacing modes except during episodes of atrial fibrillation. Each patient had had recurrent episodes of atrial fibrillation prior to pacemaker insertion. After pacemaker insertion, when atrial fibrillation occurred the pacer would not sense or capture. These episodes were controlled by electrical or drug cardioversion with subsequent return of normal pacemaker function.

Failure

Nine failures (14%) required removal of the coronary sinus lead. Four were due to dislodgement of the lead and inability to re-enter the coronary sinus. Three of these four occurred within three days of insertion and the fourth occurred after 16 months. The threshold ranged from 1.3 to 2.5 mA. Only one of these occurred with the electrode especially designed for the coronary sinus while three of 10 standard leads inserted were dislodged.

Threshold rise accounted for an additional four failures. Two occurred within three days of insertion, one at three weeks and one at two months. The initial threshold ranged from 1.8 to 2.8 mA and the threshold upon removal ranged from 9.0 to 20.0 mA. Upon repositioning, an adequate pacing threshold could not be obtained in any of these patients (fig. 2).

The remaining failure was due to the progression of A-V block three days following implantation. The initial threshold was 1.3 mA in this patient.

Degrees of Atioventricular Heart Block

There were 19 patients (29%) with evidence of A-V heart block either on resting ECG or during atrial pacing. The heart block ranged from a PR interval of > 0.22 seconds to trifascicular block or various combinations of fascicular block. An abnormal atrial pacing study was defined as A-V block occurring below a rate of 130. There were eight patients who had evidence of A-V block by resting ECG only and had a normal pacing study. Five patients with a normal resting ECG developed A-V block with pacing. Six patients had both ECG and pacing evidence of A-V block. Progression of block necessitating repositioning of the pacemaker to the right ventricle occurred in only one patient. This occurred three days after insertion of the pacemaker. This patient had the most severe degree of block for the group on both pacing study and resting ECG. She had 1° A-V block, right bundle branch block and left anterior hemiblock on her resting ECG and developed 2:1 block at a pacing rate of 90.

The follow-up period ranged from three days to 44 months. The average range of follow-up was 13.9 months. One other patient had a failure secondary to dislodgement. There were no transient pacemaker problems in this group.

Threshold

Table 1 compares the failures and transient problems to the pacemaker threshold at the time of insertion. The majority of patients 54/64 (84%) had a threshold below 3.0 MA. There were 10 patients (15%) with thresholds ranging from 3.1 to 6.0 mA. All of the failures occurred in the lower threshold group. There were no failures in the group with higher thresholds although this group was quite small. The higher threshold group had two transient threshold problems compared to three in the lower threshold group.
Pacer Spike-R Interval

Thirty-four of 66 patients had pacer spike-R interval records available for both insertion and the most recent follow-up. Twenty-four of the thirty-four (70%) patients had normal intervals that remained normal at the time of follow-up (normal defined as 0.20 sec or less). One patient with a spike-R interval of 0.20 sec had an increase to 0.30 sec but paced normally without sensing problems or development of further degrees of block. Nine patients of 34 (26%) initially had abnormally long spike-R intervals. Three of the nine at follow-up had normal intervals; five of the nine had the same intervals; only one patient had an increase in the interval from 0.24 to 0.40 sec. This patient was not sensing his own QRS. None of the patients had progression of block. Only two of the nine patients had transient problems; none had pacer failure (fig. 3).

Deaths

There were four patient deaths during the follow-up period. All records were reviewed and none of the deaths were related to pacemaker failure or progression of heart block. There were no sudden deaths. Two patients were admitted to the hospital with a cerebral vascular accident and subsequently died. One patient died after an acute myocardial infarction. One patient died of bronchopneumonia and Parkinson’s disease.

One patient who died of a cerebral vascular accident was autopsied. The coronary sinus lead had been implanted 75 months prior to death which was the longest follow-up period in this study. The postmortem examination revealed the coronary sinus to be free of clot and the lead was adherent to the walls of the coronary sinus by thin bands of fibrous tissue. The lead was not obstructing coronary flow.

Discussion

Our indications for permanent pervenous atrial pacing are similar to those reported by Moss et al.2-4 and by Furman5: ventricular arrhythmias refractory to medical management, bradycardia with ventricular escape beats, bradycardia with resultant congestive failure and low cardiac output, symptomatic bradycardia without failure, and tachycardia-bradycardia syndrome.

Transient problems consisting of threshold rise, loss of atrial pacing or migration of the catheter down the coronary sinus resulting in ventricular pacing developed in 14% of the group. These problems were corrected by reprogramming the pacemaker to higher current or repositioning the lead. In seven of nine cases these occurred early and were corrected during that hospital admission. Once these problems were corrected there were no subsequent failures. The occurrence of a transient problem was not predicted by initial threshold measurement. The incidence of early transient problems most likely relates to placing the lead in a large smooth walled vein. This may result in movement of the lead to a suboptimal or nonfunctioning position. Careful evaluation of thresholds along the coronary sinus indicated that the optimum area for threshold pacing varied greatly over small distances. A small change in the lead could result in a large increase in the pacing threshold.

Atrial pacing thresholds tend to be higher than ventricular pacing thresholds. The combination of higher thresholds and lead movement can result in early transient problems. The absence of late transient problems may be related to the adherence of the lead to the wall of the coronary sinus by fibrosis as seen in our autopsy study and reported by others.6 The pacer threshold usually remained the same when checked at the time of pulse generator replacement.

It appears that in some patients with intermittent atrial fibrillation coronary sinus pacing can provide an atrial impulse that minimizes the tendency to return to atrial fibrillation. An example of this is demonstrated by one patient in

<table>
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<th>Failures</th>
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<td>4 (7%)</td>
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Figure 3. P-R intervals during long-term follow-up. The normal P-R intervals remained normal. The prolonged P-R intervals remained the same or decreased to normal. One prolonged P-R had further progression and one normal P-R became abnormally prolonged.
this study who had refractory atrial fibrillation and congestive failure. Repeat attempts at cardioversion failed to maintain a sinus rhythm. Cardioversion followed by immediate coronary sinus pacing resulted in maintenance of a sinus rhythm for 29 months. The addition of his atrial transport mechanism has increased his cardiac output to where he now maintains satisfactory compensation.

Failure to sense the atrial electrogram was not a significant problem in our series. Theoretically a supraventricular tachycardia can be induced by a nonsensing atrial pacemaker. However, we did not find an increased incidence of supraventricular tachycardia in the five patients with failure to sense the atrium. Pacemaker-induced ventricular arrhythmias are not a problem with an atrial pacemaker. In three patients the onset of atrial fibrillation was associated with a failure to sense or capture the atrium. After electrical or medical cardioversion the pacemaker functioned normally.

There was an overall 14% failure rate of coronary sinus pacing which is similar to a previous series by Moss. In four of the patients there was a threshold rise and attempts at repositioning the lead revealed an elevated threshold along the entire length of the coronary sinus or great cardiac vein. This has been reported by others; its cause is unknown. An additional four patients had coronary sinus dislodgement and the coronary sinus could not be re-entered. In three of these patients the dislodgement occurred early and was probably related to catheter movement. The fourth patient had a late dislodgement after 16 months. In this case there was evidence of failure to pace while the patient was standing; under fluoroscopy the lead was seen to move back and forth in the coronary sinus. It is likely that continued lead movement in the coronary sinus prevented it from adhering to the wall. One patient had advanced A-V block requiring conversion to a right ventricular pacemaker after three days.

It is important to note that during an average follow-up of 14 months after pacemaker implant there was a 21% likelihood of a second operative procedure to revise the system to correct a transient problem or to remove the system because of an uncorrectable pacemaker failure. These included nine failures as outlined above and five transient correctable problems requiring repositioning of the coronary sinus lead.

In our series 29% of the patients had evidence of a varying degree of A-V block. There have been previous reports in the literature indicating caution against atrial pacing in patients with this condition. Moss has indicated that patients with a P-R interval greater than 0.26 or atrial pacing inducing fascicular or bundle branch block are relative contraindications to atrial pacing. In our experience patients with prolonged P-R interval, bundle branch block, bifascicular block, trifascicular block, and 2:1 atrioventricular block on atrial pacing below a rate of 130 were successfully paced from the atrium in all but one case. In this case there was trifascicular block and 2:1 atrioventricular block at a pacing rate of 90. Our experience indicates that despite evidence of A-V block, long-term successful atrial pacing can be accomplished if the atrial pacing study indicates 1:1 conduction above a rate of 100. These patients were paced from the coronary sinus because of the need demonstrated clinically for the atrial contribution to ventricular performance. In our experience, these patients have continued with satisfactory pacing without the progression of A-V block. To date there have been no other published studies on atrial pacing in the presence of A-V block. In selected cases where the atrial contribution to ventricular filling clearly improves clinical status, this may be attempted. However, frequent follow-up is mandatory to detect progression of A-V block. Since a 14-month follow-up period may not be sufficient to evaluate progression of A-V block, further studies with longer follow-up periods are needed to determine the feasibility of atrial pacing in the presence of A-V block or sick sinus syndrome before this can be routinely recommended.

In 54 of 66 patients the implantation threshold was 3.0 mA or less. Moss has indicated in his series that higher thresholds can lead to further pacing problems. In our series 10 patients had thresholds from 3.1 to 6.0 mA. None of these patients had a subsequent failure and only two had transient threshold rises. There was no correlation between initial pacing threshold and the development of further pacing problems. We conclude that a threshold between 3.0 and 6.0 mA does not preclude successful pacing from the coronary sinus.

The pacer spike-R interval at implantation and follow-up was recorded in 34 patients. The spike-R interval tended to remain stable at follow-up. Patients with a normal spike-R interval tended to remain normal. Those with prolonged intervals tended to remain the same or decrease to normal. One patient from each group had significant prolongation of the spike-R interval but this did not present difficulties. Excessively prolonged spike-R intervals beyond the pacer refractory period may result in sensing the R wave with resultant bradycardia. This occurred in two cases in our series. Digitalis will often prolong the A-V interval and in one case, a reduction in dosage eliminated the problem. One patient had a spike-R interval of 0.4 sec. but did not have slowing of the pacer rate which indicated a failure to sense the ventricle.

The four deaths that occurred in our series were not pacemaker related. There was no perforation or thrombosis of the coronary sinus. We conclude that coronary sinus pacing is a safe and effective means of stimulating the atrium and in many cases is preferred over ventricular pacing.

References

Atrial Pacing from the Coronary Vein

Ten-year Experience in 50 Patients with Implanted Pervenous Pacemakers

ARTHUR J. MOSS, M.D., AND ROBERT J. RIVERS, JR., M.D.

SUMMARY During the past ten years, pervenous atrial pacemakers have been implanted in 50 patients (mean age 68 years, 60% males) using an electrode positioned in the coronary vein. The indications for atrial pacing were symptomatic sinus bradycardia (72%), atrial brady-tachy syndrome (20%), and recurrent tachyarrhythmias (8%). Atrial pacemakers have been implanted for a total of 1531 pacing months, average 31 months per patient, median 26 months, and range 3–97 months. Effective atrial pacing has been achieved with Medtronic model 5818 and 6904 electrodes. Unipolar or bipolar atrial pacing has been equally effective, and commercially available Medtronic 5950, Cordis 162 and CPI 602 pulse generators have been utilized without difficulty. A total of 11 electrode related malpacing events occurred in the ten-year period with a malpacing event rate of 10% in the first pacing month, 1.1% per paced month during the next six months, and 0.25% per paced month thereafter. Life table analysis reveals that effective atrial pacing was achieved in 76% of the patients during a follow-up of more than five years. This experience substantiates the long-term safety and effectiveness of atrial pacing from the coronary vein using standard pacemaker electrodes and generators.

Methods

Details of the method of implanting a permanent coronary venous atrial pacemaker have been described previously from this laboratory.1–4 Presently, the most effective technique for introducing the catheter into the coronary vein utilizes a left cephalic vein approach. With rare exceptions, Medtronic model 5818 and 6904 bipolar catheters have been utilized. A gentle 60° bend 6 cm back from the tip of the electrode and an additional J bend at the electrode tip are made with the stylets in the catheter before insertion of the electrode into the vein. The catheter is advanced under fluoroscopic visualization into the right atrium, and with the aforementioned bends in the electrode the catheter is directed away from the tricuspid valve and into the coronary sinus. The characteristic superior direction of the electrode in the coronary vein is well described in previous reports.5, 6 The fluoroscopic time for positioning the catheter in the coronary vein is generally less than five minutes. After the catheter is in the mid portion of the coronary vein, the stylets are withdrawn and the threshold for pacing is determined for the unipolar proximal (ring) and distal (tip) electrodes and for the bipolar configuration. The lowest atrial pacing thresholds have generally been obtained from the unipolar ring electrode. A threshold of less than 3 milliamps for atrial pacing is optimal, and if higher thresholds are evident the catheter is either advanced further into the coronary vein or withdrawn slightly from its prior position to obtain a lower threshold. Unipolar and bipolar pulse generators have been utilized, and satisfactory atrial pacing has been achieved with Medtronic, Cordis, and Cardiac Pacemaker pulse generators.

Results

The clinical characteristics of the 50 patients with implanted atrial pacemakers are presented in Table 1. The mean age of the patients was 68 years; 60% were males. The major indication for atrial pacing was symptomatic sinus bradycardia (72%); 20% had the atrial brady-tachy syndrome, and 8% required atrial pacing for inhibition or termination of intractable or recurrent tachyarrhythmias (ventricular fibrillation in three and paroxysmal supraventricular