His bundle electrocardiography during routine left heart catheterisation¹

WILLIAM R. CABEEN, JR. AND REX. N. MACALPIN

From the Department of Medicine, UCLA School of Medicine, Los Angeles, California 90024, USA

SUMMARY The value of His bundle electrogram recording has been previously established. A technique to allow routine inclusion of brief duration His bundle electrogram recording during retrograde left heart catheterisation has been developed using a standard pigtail ventriculography catheter with the addition of a 'Y' hub fitting providing a sealable port for introduction of an electrode wire and a side arm for continuous pressure monitoring and flushing. With the catheter in place the electrode wire is advanced to the level of the proximal side hole of the catheter and provides a unipolar intracavitary lead. Positioned to record the His bundle electrogram the catheter lies with the proximal hole (and electrode tip) just below the aortic valve leaflets. The position is stable and the left bundle-branch is not recorded. In 24 of 27 patients reliable His bundle electrograms were recorded by this technique and verified by simultaneous standard His bundle electrograms recorded from the right heart and with atrial pacing. Satisfactory His bundle electrograms were most easily obtained in patients with vertical hearts. Those few in whom it was more difficult or unobtainable had horizontal hearts.

With this technique His bundle electrogram recording can easily be added, in suitable patients, to routine left heart catheterisation at the time of ventriculography without requiring additional venous catheterisation, especially when the latter is not feasible or when only brief duration His bundle electrograms are required.

Introduction

Although His bundle potentials had been recorded by several workers with other methods before 1968 (Burchell *et al.*, 1953; Alanis *et al.*, 1958; Hoffman *et al.*, 1959; Giraud *et al.*, 1960a; Hoffman *et al.*, 1960, 1963), it was in that year that Scherlag *et al.* (1968) reported a catheter technique for recording the His bundle electrograms in the dog. This was followed shortly by the description of a similar technique in man (Scherlag *et al.*, 1969b). Since then there has been widespread use of this technique which consists of placing an electrode catheter via the venous system (usually femoral vein) across the tricuspid valve orifice adjacent to its septal leaflet in the area of the atrioventricular node—bundle of His (Scherlag *et al.*, 1969b; Scherlag and Berbari, 1975). These studies have allowed more precise localisation of the site of conduction

abnormalities in patients with various forms of heart block and a better understanding of the mechanisms and treatment of arrhythmias. In individual patients this has allowed a more appropriate choice of therapy and better prognostication. It has also allowed confirmation of many of the earlier brilliant deductions made by clinical electrocardiographers using the surface electrocardiogram. But at the same time His bundle electrograms have resulted in a greater appreciation of the limitations of surface electrocardiograms. Thus, His bundle recordings are now commonly used in the complete evaluation of patients with conduction system disease or arrhythmias.

Left ventricular intracavity electrograms have been made by many investigators in the past (Sodi-Pallares *et al.*, 1948; Gibert-Queralto, 1950; Limón *et al.*, 1950; Sodi-Pallares *et al.*, 1950; Coelho *et al.*, 1951; Steinberg *et al.*, 1951; Zimmerman and Hellerstein, 1951; Hecht *et al.*, 1957; Dickens *et al.*, 1959; Testelli, 1959), and there have been a few reports of alternate approaches to His bundle recording from the left heart and arterial system (Scherlag *et al.*, 1969a; Narula *et al.*,

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1970; Parameswaran *et al.*, 1970; Scherlag *et al.*, 1971). This approach has been little used clinically because of the need for arterial catheterisation, with its attendant risks and morbidity. However, patients who require left heart catheterisation for evaluation of coronary or valvular disease frequently also have evidence of conduction disease that warrants His electrogram recording.

We have recently developed a technique which permits the quick, safe, and reliable recording of His bundle potentials from the left heart during routine left heart catheterisation. The technique, verification of the identity of the events recorded, and our initial experience are the subjects of this communication.

Method

The principle of the technique is the passage of a wire electrode down the lumen of a previously positioned ventriculography catheter so that the tip of the wire just reaches its proximal side hole. The catheter electrode system is then positioned at the appropriate level just below the aortic valve leaflets where recordings of the His bundle electrogram can be made.

The electrode consists of an appropriate length (about 110 cm) of 27 gauge stainless steel needle wire 0.016 in in diameter. The distal end is rounded (with emery paper and jeweller's rouge) to prevent catheter perforation. The proximal end is bent at right angles to provide a stop which prevents the

distal end of the wire from being advanced beyond the most proximal side hole of the catheter (Fig. 1).

The catheter used is a standard 110 cm long 'pigtail' ventriculography catheter made of polyethylene; there are multiple side holes between 13 mm and 37 mm from the distal end (Cook, Inc., Bloomington, Indiana). It is similar to that described for ventriculography by Judkins (1968). A special catheter hub adapter provides a sealable port for introduction of the electrode and a side arm for continuous pressure monitoring and flushing. This adapter is fashioned out of a Y fitting (Seldon mixing adapter) and a small male Tuohy-Borst adapter (Becton-Dickinson, Rutherford, N.J.) (Fig. 1). When in position the proximal end of the wire is connected to a suitably isolated electrocardiograph amplifier via a sterile lead wire. We have chosen to record this left ventricular electrogram as a unipolar lead referenced to a central terminal (Wilson *et al.*, 1934). However, no differences in timing and only minor differences in configuration of the electrogram result from referencing the cavitory lead to a single lead anywhere on the body surface. The unipolar lead recording system is used rather than a bipolar one in order to allow use of a single wire in the pigtail catheter as described. That the His electrogram obtained with this unipolar approach is as reliable as bipolar recording is discussed below.

In practice, the patient is prepared for left heart catheterisation in the usual fashion. Surface electrocardiographic leads are placed to allow simultaneous monitoring of several leads (e.g. I, aVF, V₁) as well as to provide the central terminal for the intracavitary-His recording lead. The electrode wire is tested in the pigtail catheter to be used to assure that, when inserted, its end will reach just to the level of the most proximal side hole with the right angle bend of the proximal end flush against the adapter (Fig. 1). The electrode wire is then removed from the catheter, the catheter is introduced percutaneously by the Seldinger technique (Seldinger, 1953), and the patient is heparinised (usually with 50 U/kg). After the catheter has been passed retrogradely across the aortic valve and into the left ventricular cavity, the electrode wire is reintroduced into the catheter with the use of the sealable adapter, and is then connected to the electrocardiograph amplifier. Pressure monitoring and flushing of the catheter are maintained via the adapter's side arm. While recording the left ventricular intracavitary electrogram and pressure, the catheter-electrode system is manipulated so that the proximal side hole (and electrode tip) lies just below the aortic valve leaflets and against the inter-ventricular septum at the level of the membranous

Fig. 1 The catheter-electrode system. Shown are the pigtail catheter, the sealable adaptor with the electrode wire in place for recording, and the attached manifold providing connections for pressure monitoring, a syringe, and sources of saline for flushing and radiographic contrast medium for subsequent angiography.

Fig. 2 Left: X-ray showing right and left sided electrode catheters in recording position. Right: Schematic representation of catheter position for recording. Note the ability to place electrodes adjacent to the His bundle from either the right or the left heart. In recording position the left sided pigtail catheter lies with the proximal side hole (and thus the electrode tip) within the left ventricular cavity, just below the aortic valve leaflets and adjacent to the His bundle. (AO = aorta, IVC = inferior vena cava, LA = left atrium, LV = left ventricle, MV = mitral valve, TV = tricuspid valve).

septum (Fig. 2). Pressure recording via the catheter aids in this placement because the His electrogram is usually obtained when the catheter is as high as possible in the outflow tract while still recording left ventricular pressure. After completion of the intracardiac electrocardiographic studies, the wire electrode is removed and left ventriculography is carried out in the usual fashion through the same catheter. Though it is theoretically possible that catheter manipulation against the His bundle or left bundle-branch might cause transient conduction block, similar to the right bundle-branch block which occurs occasionally with right heart catheterisation, this was not seen. As the manipulation of the pigtail catheter is no more involved than that usually required for ventriculography, where catheter induced block is seldom if ever seen, this theoretical possibility in fact is extremely unlikely.

While developing the technique described we also recorded His bundle electrograms simultaneously from the right heart using standard methods (Scherlag *et al.*, 1969b; Scherlag and Berbari, 1975), taking precautions not to record the right bundle-branch. This provided the major confirmation of the identity of the electrograms recorded from the left heart (Fig. 3). In addition right atrial

pacing using standard techniques was carried out in several cases (Fig. 4).

In this study all electrograms and pressures were recorded on an Electronics for Medicine DR-8 recorder with a 'Rapid-Writer' Model RWR paper printout with paper speed of 100 mm/s. Measurements of intervals were made directly from these records. The onset of the His deflection was taken as the first rapid deflection recorded and was measured with an accuracy of ± 2 ms.

Recordings in the left heart were made with low and high frequency cutoff filters set at 0.1 and 250 Hz respectively for 'high fidelity' recordings, and at 40 and 500 Hz respectively when 'standard' His bundle recordings were desired. Occasionally large amplitude 60 Hz noise necessitated recording only between 0.1 and 25 Hz. Great care was required to keep lead wires away from power lines in order to minimise 60 Hz artefact. When such artefact could not be avoided, interposition of a 60 Hz notch filter in the output circuit was very effective in allowing us to obtain adequate tracings. Reliable His electrograms of sufficient amplitude were recorded at all filter settings used. Gain settings required varied from 0.25 to 4.0 mV/cm but were usually 1.0 to 2.0 mV/cm.

Fig. 3 Simultaneous His electrograms recorded from the right heart (R HBE) and left heart (L HBE) with the left sided electrogram recorded at filter settings of 0.1-25 Hz in (a) and 40-500 Hz in (b). Also recorded are three surface leads I, aVF, and V₁, high right atrial activity and left ventricular pressure monitored through the same catheter in which the left-sided electrode is placed. Gain settings: L HBE = 1 mV/cm, R HBE = 5 mV/cm. (A = atrial electrogram, H = His electrogram, HRA = high right atrial electrogram, L HBE = His bundle electrogram recorded from the left heart, R HBE = His bundle electrogram recorded from the right heart, LV = left ventricular pressure.)

Fig. 4 His bundle electrograms recorded from the left (L HBE) and right (R HBE) heart before (a) and during (b) right atrial pacing at 130/minute. Note that during atrial pacing the AH interval lengthens but the HV remains unchanged in both the right and left sided recordings. Also recorded are surface leads I, aVF, and V₁, high right atrial activity (HRA) and left ventricular pressure (LV). (abbreviations and gain settings as in Fig. 3; filtering 40 to 500 Hz).

Results

To date 27 adult patients between the ages of 34 and 71 have been studied by this technique. In all patients, the overall catheterisation was prolonged only about 10 minutes because of recording left ventricular cavity potentials, and there were no complications caused by this procedure. Successful recording of the His bundle electrogram was

achieved in 24 of these. The 3 unsuccessful attempts occurred in patients with 'horizontal' hearts early in the development of the technique while optimal positioning techniques were being learned. Now, though patients with horizontal hearts sometimes require additional catheter manipulation, adequate recordings can be obtained in almost all patients without difficulty. In most cases (20 of 24) the deflection recorded in the PR segment from the left

ventricle was simultaneous with the His potential recorded from the right ventricle (Fig. 3). In 4 patients the onset of the right and left-sided His deflections differed by up to 5 ms. This is probably because of the 2 electrodes recording proximal and distal portions of the His bundle (Narula, 1975a) or perhaps because of unrecognised 'split His' potentials in these patients (Narula, 1975b; Schuilenburg and Durrer, 1975a). Left bundle-branch potentials were not and could not be recorded.

His bundle pacing was attempted via the left sided electrode in some patients but was not successful in selective pacing of the His bundle or the left bundle-branch (ventricular pacing was obtained), probably because the electrode was, by necessity, not in direct endocardial contact.

Atrial pacing, however, supported the identity of the left sided deflection as a His bundle potential. As the atrial pacing rate was increased, the AH interval became prolonged as expected (Damato *et al.*, 1969); the HV interval remained constant, identical to the events recorded from the right heart (Fig. 4).

Although the left His recording as described is unipolar, the right His recording was made in a bipolar fashion with 1 cm electrode separation and also in a unipolar fashion from both the proximal and distal electrodes of the right sided catheter (usually a Zucker catheter). Both the unipolar and bipolar recordings from the right were simultaneous with the left sided recordings (Fig. 5). The unipolar recording from the proximal right electrode was

usually of small amplitude and that from the distal electrode was large and similar to the bipolar right electrogram (a finding similarly found and reported by Schuilenburg and Durrer, 1975b, and by Hope *et al.*, 1974).

Discussion

Despite the expanding clinical use of His bundle recording from the right heart, there has been little clinical use of His bundle recording from the left heart since its initial descriptions (Scherlag *et al.*, 1969a; Narula *et al.*, 1970; Parameswaran *et al.*, 1970; Scherlag *et al.*, 1971). This is quite understandable because His bundle recording alone can be done easily and with less morbidity from the right heart. Arterial catheterisation is not justifiable for His bundle recording alone. However, when patients who require left heart catheterisation for other aspects of their heart disease also would benefit from brief recording of their His bundle potentials, the left heart approach as described here may be a more convenient method. It requires no additional catheters and can be performed quickly and reliably, and with the patient systemically heparinised it can be accomplished with no significant risk over and above that intrinsic to the left ventricular catheterisation itself.

As described, the identity of the deflection recorded from the left heart was confirmed by its simultaneity with the His bundle deflection recorded from the right heart by accepted techniques, that is by similar configuration and duration of the right

Fig. 5 Comparison of unipolar and bipolar recordings. The upper tracing shows the standard left sided unipolar recordings as used in this study. The next (left-right bipolar) shows the bipolar electrogram obtained by recording between the distal electrode of the right sided catheter and the left sided electrode. The 3rd recording is a unipolar electrogram from the distal electrode of the right sided catheter. Note simultaneous His electrograms in each case. Also recorded are right and left ventricular pressures from the respective catheters. (Abbreviations as in Fig. 3; RV = right ventricular pressure recorded via the right sized (Zucker) electrode catheter.) Filter settings: 40 to 500 Hz. Gain: 0.25 mV/cm.

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and left sided recordings and by a stable HV interval with increase in the AH interval during atrial pacing.

Unipolar electrograms, as in this study, have been shown by others to be as reliable and accurate as bipolar electrograms for recording His bundle activity. In fact, most so-called bipolar recordings are probably effectively unipolar from the electrode of the pair that is closest to the His bundle (Giraud *et al.*, 1960b; Hope *et al.*, 1974; Moore *et al.*, 1974; Roberts, 1975; Scherlag and Berbari, 1975; Schuilenburg and Durrer, 1975b). The findings reported here support this. Our bipolar right heart and unipolar left heart His bundle recordings were essentially the same in timing. In addition, unipolar recording from the distal electrode of the right heart catheter and bipolar recordings between the distal right electrode and the left sided electrode all gave similar results (Fig. 5).

Fig. 2 shows the pigtail-electrode system and the right sided His bundle catheter in recording position. As can be seen the electrode catheters lie perpendicular to each other with the electrodes at the same level, but, of course, on opposite sides of the interventricular septum. The His bundle runs through the base of the membranous septum or along (usually on the left side, occasionally on the right side) the crest of the muscular septum (Titus, 1973; Massing and James, 1976). Narula *et al.* (1970) have previously described *bipolar* His bundle recording from the left heart in man using standard bipolar electrode catheters with findings similar to ours. They recorded His potentials at the level of the aortic cusps (though not specifically stated, the catheter tip was probably in a sinus of Valsalva). In one patient His potentials were recorded just below the aortic valve. Similarly Scherlag *et al.* (1971) describe bipolar recordings of His activity in the dog with the tip of the electrode catheter within the aortic root at the base of the right coronary cusp close to the non-coronary cusp. When their catheter was advanced to a stable position in the left ventricle, left bundle-branch potentials were recorded. The apparent difference in successful recording site, we feel, is because of the difference in catheter systems used. The straight electrode catheter can be made stable in the sinus of Valsalva which is close enough to the membranous septum (through whose base the His bundle runs) (Massing and James, 1976) to allow recording of His potentials. In order to be stable when advanced through the aortic valve a straight catheter must be some distance into the ventricle with its tip against the septum. This necessarily results in the tip being at least 1 to 2 cm into the cavity, resting against the muscular septum some distance below the His

bundle. Therefore, left bundle potentials are recorded. With the pigtail catheter system, the electrode is on the shaft of the catheter (at the proximal side hole). The electrode cannot, therefore, be positioned in the sinus of Valsalva but with the catheter across the valve, lying in the commissure between the right and non-coronary cusps, it can be positioned precisely with the electrode at the level of the junction of the membranous muscular septa where the His bundle lies. With vertical hearts this positioning is straightforward; with very horizontal hearts it requires some rotation of the catheter so that its shaft at the level of the electrode will lie near the septum.

Left bundle-branch potentials were not recorded in our studies. This is probably because as the catheter is advanced with the pigtail leading, the shaft is brought more into the centre of the cavity and, therefore, cannot be close enough to the arborising left bundle conduction tissue to record its activity.

In conclusion, the technique described provides a quick, safe, and reliable method for recording the His bundle electrogram during routine left heart catheterisation, allowing the collection of additional valuable information with no added risk and little added effort or time. This can be achieved without introduction of an additional venous catheter. This technique will perhaps be most useful in evaluating patients who have, in addition to disease requiring left heart catheterisation for collection of haemodynamic and angiographic data, conduction disease for which recordings of the His bundle electrogram would provide a more complete picture. If, as is not infrequently the case during His bundle studies, additional electrodes are required for atrial pacing and recording of high right atrial activity or left atrial activity (usually via the coronary sinus), they can be placed through the veins in the usual fashion. In many patients who have compound cardiological problems requiring standard right and left heart catheterisation as well as His bundle recording for complete evaluation, this can be efficiently achieved by recording the His bundle potentials from the left heart as described and pacing and recording the right atrial electrogram using a quadripolar catheter introduced by the single venous route also used for the right heart catheterisation. Of course, if the data required of the His bundle study would in itself require a significant amount of time for collection, then it would be more appropriate to do this as a separate study because of the resultant substantial increase in arterial catheterisation time, and also because the addition of this time to that required for the angiographic—haemodynamic study would result in an unacceptably long procedure.

On the other hand, the ability to record His bundle activity reliably from the left heart may be particularly useful in special situations where right sided recordings are difficult such as in patients with a tricuspid valve prosthesis, extensive venous disease, or inferior vena cava plication. Similarly, the described technique for left sided His bundle recording is precluded in patients with an aortic valve prosthesis and is difficult in patients with significant aortic valve deformity.

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- Requests for reprints to Dr William R. Cabeen, Jr., Department of Medicine, UCLA Center for Health Sciences, Los Angeles, California 90024, U.S.A.