Direct Current Conversion of Atrial Fibrillation

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Lown et al. (1962b) demonstrated the safety of direct current shock and its effectiveness in abolishing ventricular fibrillation. Soon afterwards the use of this method was extended to the treatment of atrial fibrillation (Lown, Amarasingham, and Neuman, 1962a). The direct current shock causes complete depolarization of cardiac muscle, allowing the sinus node to take over as pacemaker. The safety of the method depends on careful synchronization of the direct current discharge to avoid the vulnerable T period of the cardiac cycle. Several papers (Killip, 1963; Lown et al., 1963; Oram et al., 1963; McDonald, Resnekov, and O'Brien, 1964) reported a high percentage of successful conversions and minimal complications.

This article deals with results and follow-up of 175 patients in whom abolition of atrial fibrillation by direct current shock was attempted. The results of conversion in some of these patients have already been reported (Pantridge and Halmos, 1965).

SUBJECTS AND METHOD

There were 118 women and 57 men, with an age range from 22 to 60 years and a mean age of 48·2 years. Of these patients, 140 had rheumatic heart disease, 17 had evidence of myocardial ischæmia, 8 had a history of treated thyrotoxicosis, and 4 had idiopathic atrial fibrillation. Congenital heart disease and constrictive pericarditis were the cause of the arrhythmia in 3 and 4 patients, respectively. The disability of each patient was graded according to the New York Heart Association (1953) classification: 145 were in grades I and II, and 30 in grades III and IV. In 127 patients mitral valvotomy had been performed: 2 had an atrial septal defect closed under hypothermia, and one had a patent ductus arteriosus resected. Atrial fibrillation had been present from 2 weeks to 20 years, with an average duration of 3·36 years.

The methods of conversion and of anæsthesia have already been described (Pantridge and Halmos, 1965). The cardiogram of each patient was classified before conversion into groups according to the type of F waves observed in lead V1. Those patients with minimal and no fibrillating activity were classified as Group I, while those with fibrillating waves of 1 mm. or more constituted Group II. Following successful conversion the first 56 patients received quinidine sulphate gr. 5 four times daily, the next 41 effervescent potassium, 2 tablets four times daily, while the last 40 patients were on no maintenance therapy. Quinidine therapy had to be discontinued due to toxicity in 4 patients. Anticoagulants were not used. In 10 patients cardioversion was performed without anæsthesia. Patients were reviewed at 1, 4, 8, 12, 24, and 36 weeks after conversion. They were also asked to attend immediately should they suffer palpitations or sudden breathlessness.

RESULTS AND FOLLOW-UP

Of the 175 patients with atrial fibrillation, sinus rhythm was established in 137 (78%). Atrial fibrillation persisted in the remaining 38 patients. Altogether there were 295 attempts at establishing sinus rhythm—88 patients receiving one shock, 58 two, 25 three, and 4 patients four shocks. Most patients converted at low energy levels (100–200 watt seconds). Only 15 per cent of patients required the maximal 400 watt seconds shock.

Best results were obtained in patients whose atrial fibrillation was associated with treated thyrotoxicosis. The different groups are shown in Table I. The difference between the rheumatic (79%) and non-rheumatic (77%) groups was small. Cardiac size as judged by the cardiothoracic ratio had an influence on the results. In patients with a cardiothoracic ratio of over 0·55 the success rate of conversion was significantly smaller (p= 0·01–0·02). Sex and age incidence did not appear to influence the result of conversion. The duration of atrial fibrillation had a marked effect on the results. While 90 per cent of patients with atrial fibrillation

TABLE I

EFFECT OF ÆTIOLOGY OF ATRIAL FIBRILLATION ON SUCCESS OF CONVERSION

	No. of patients	Successful conversion	Failed conversion
Rheumatic heart disease ..	140	110 (79%)	30
Thyrotoxic heart disease ..	8	7 (88%)	1
Ischæmic heart disease ..	17	13 (77%)	4
Congenital heart disease ..	3	2 (67%)	1
Idiopathic atrial fibrillation	4	3 (75%)	1
Constrictive pericarditis ..	3	2 (67%)	1

TABLE II

ELECTROCARDIOGRAPHIC ABNORMALITIES OCCURRING WITHIN 10-MINUTE INTERVAL AFTER CONVERSION

Electrocardiographic abnormality	No. of patients
Absent	100
Present	75
P wave abnormalities	15
Ventricular extrasystoles	20
Atrial extrasystoles	38
Nodal extrasystoles	6
Nodal rhythm	5
Sinus tachycardia	4
Atrial flutter	3
Supraventricular tachycardia	6
ST depression	6
Increase in voltage of QRS	3

of less than 5 years converted to sinus rhythm, this figure dropped to 27 per cent if atrial fibrillation had lasted more than 5 years. There was a higher incidence of failed conversion in patients with predominant mitral incompetence than in those with pure mitral stenosis or minimal incompetence.

Statistical differences were found between the results in patients with different size of F waves—36 per cent of patients in Group I failed to convert, but only 17 per cent of those in Group II ($p = 0.02$–0.05) (Fig. 1). Electrocardiographic abnormalities were frequent following conversion, but generally not serious. The summary of the various arrhythmias occurring within a 10-minute interval is given in Table II. The distribution of P-R intervals in this study, among 200 hospital controls and among the cases of Graybiel *et al.* (1944), is shown in Fig. 2. The incidence of prolonged P-R interval was significantly higher among the converted patients ($p < 0.001$). The adverse effect of digitalis toxicity on the success of conversion has previously been reported (Pantridge and Halmos, 1965). There is, however, another important indication for avoiding over-digitalization. The only important complications immediately following conversion (Stokes-Adams attacks due to nodal rhythm,
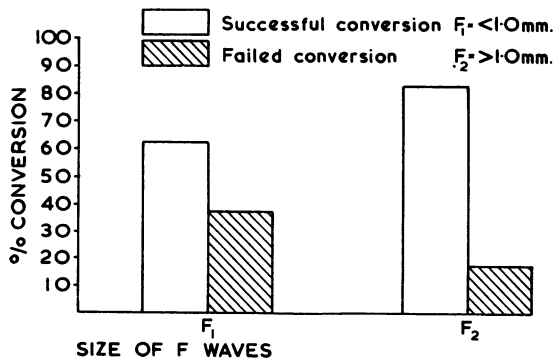
numerous multifocal extrasystoles) occurred in patients who had signs of digitalis toxicity.

One patient developed aphasia and weakness of his right arm 24 hours after conversion, but there was complete recovery from this embolic episode within 15 minutes. One patient died suddenly 12 hours after sinus rhythm had been established. The necropsy showed no evidence of embolization or of myocardial damage. In the absence of positive findings it was assumed that the cause of death in this patient was quinidine sensitivity. In 25 patients who reverted to atrial fibrillation 1 to 5 weeks after conversion a further attempt at establishing sinus rhythm was completely successful.

All patients have now been followed-up for at least 9 months. Less than half (42%) are still in sinus rhythm. Reversion to atrial fibrillation is high in the first week following conversion, decreasing rapidly thereafter. The follow-up data
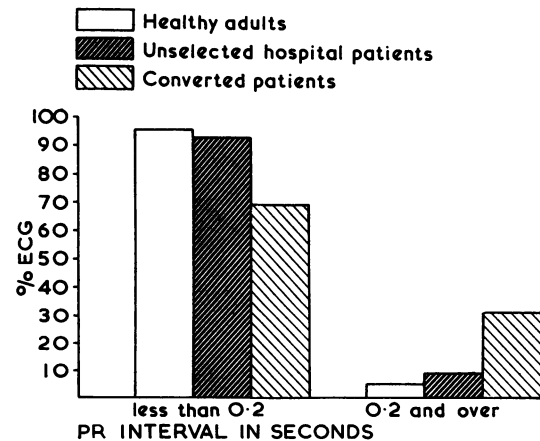

FIG. 1.—The effect of the size of fibrillating F waves on the success of conversion.

FIG. 2.—Shows that the incidence of a P-R interval of 0·2 second or over was higher in converted patients than in two groups of controls.

for this period are shown in Fig. 3. The difference between the percentage of patients in sinus rhythm after 3 months in the 3 groups on different maintenance therapy was small (57, 56, and 53%).

At the 4-week follow-up all patients were asked if any improvement had been noted. Of 87 patients in sinus rhythm at that time, 68 noted improvement, 13 noticed no change, and 6 complained of not feeling as well as they had before conversion. The reappearance of uncontrolled atrial fibrillation caused congestive heart failure and necessitated readmission to hospital in 4 patients.
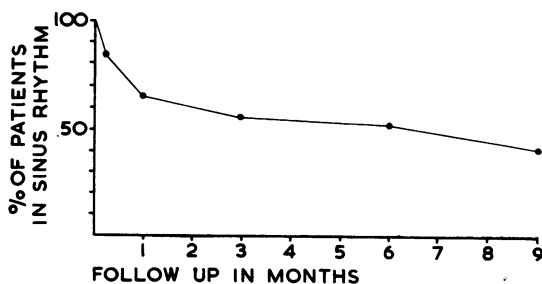

FIG. 3.—Results of follow-up 9 months after conversion.

DISCUSSION

When considering the advantages and disadvantages of a new method of converting atrial fibrillation to sinus rhythm, the first question that needs to be answered is whether abolition of atrial fibrillation is beneficial.

Atrial fibrillation is thought to have an adverse effect on efficiency of circulation. Most studies (Kory and Meneely, 1951; Broch and Müller, 1957; Gilbert et al., 1963) agree that the cardiac output is increased when atrial fibrillation is abolished. Dyspnœa, palpitations, substernal discomfort, and anxiety are common complaints, particularly in the early stages of atrial fibrillation. When sinus rhythm is established the patient often feels better and his exercise tolerance is improved. In this study, conspicuous subjective improvement was found one month after conversion to sinus rhythm. This may be due to the disappearance of palpitations, to an improved cardiac output, and partly to psychological factors.

The harmful effects of atrial fibrillation are even more pronounced on exertion since the rise in ventricular rate following exercise is significantly higher in patients with well-controlled atrial fibrillation than with sinus rhythm (Blumgart, 1924; Knox,

1949). Long-standing atrial fibrillation may, even in the absence of other cardiac involvement, lead to cardiac dilatation and failure (Phillips and Levine, 1949). Pulmonary infarction may rapidly follow the onset of atrial fibrillation due to stasis and thrombus formation in the right atrium or in a branch of the pulmonary artery (Fraser and Turner, 1955). In a well-compensated patient the sudden onset of rapid atrial fibrillation may produce severe congestive heart failure. Cases have, however, been described where atrial fibrillation persisted for years without producing cardiac enlargement or serious incapacity (Hanson and Rutledge, 1949; Riss and Levine, 1957).

The danger of atrial fibrillation due to rheumatic heart disease is related to the high rate of systemic embolization (Sokolow, 1951; Fraser and Turner, 1955). The risk of emboli immediately following quinidine conversion was found to be much smaller than the over-all risk of embolization if the fibrillation persists (Goldman, 1960). There can be little doubt that experimental and clinical evidence favours the view that establishment of sinus rhythm is beneficial.

In this study, direct current conversion was found to be effective in abolishing atrial fibrillation. Sinus rhythm was established in 78 per cent of patients. Impressive results with successful conversions of 83–90 per cent of patients have been reported by Lown et al. (1963), Killip (1963), and Oram and Davies (1964). The best results are obtained in patients in whom atrial fibrillation developed after mitral valvotomy. Many of these patients tend to revert to sinus rhythm spontaneously and for this reason it is best to postpone direct current conversion for 14 days after operation. By this time over 90 per cent of those who convert spontaneously will be in sinus rhythm, thus the unnecessary use of direct current shock is avoided. It was found that predominant mitral incompetence reduces the chances of a successful conversion.

Oram and Davies (1964) found a slightly higher conversion rate in patients whose atrial fibrillation was due to rheumatic heart disease. Atrial fibrillation due to previous thyrotoxicosis gave the best results in this study but the results were similar irrespective of the ætiology of atrial fibrillation.

Oram and Davies (1964) found it more difficult to convert patients over the age of 50, but cardiac size did not affect their results. The present study demonstrated no difference between patients who were less than 45 years of age and patients over that age. It was often surprising how easily patients over 60 years of age converted to sinus rhythm. Patients with large hearts (cardiothoracic ratio of over

0·55) were more difficult to convert. Even in this group, sinus rhythm was established in 65 per cent.

It has been noted by Rokseth and Storstein (1963) that there is an inverse relation between the duration of atrial fibrillation and the success of quinidine conversion. Yount, Rosenblum, and McMillan (1952) could find no difference in their results when comparing patients with atrial fibrillation of less than 6 months' with those of over 2 years' duration. However, they give no data of the exact duration of atrial fibrillation when present for over 2 years. It was established in this study that atrial fibrillation of over 5 years' duration had an adverse effect on the success of direct current conversion. Only minimal differences were found when patients with atrial fibrillation of 2 to 5 years' duration were compared with those of less than 6 months. These findings are of importance and should be borne in mind when a patient is considered for direct current conversion.

The energy required for successful conversion varies with the individual patients. Most patients (77%) converted at an energy level of below 200 watt seconds. Of Lown *et al.*'s (1963) patients, 74 per cent converted with similar discharges. Peleška (1963) examined the occurrence of cardiac arrhythmias following condenser discharges and found that the deleterious effects of electrical currents of the intensity necessary for defibrillation depend mostly "on the overall energy levels, the voltage and the condition of the myocardium". It was also our experience that with repeated shocks and increasing energy levels the number of ventricular extrasystoles increased, and that increase in ST segment depression only occurred after a 400 watt second shock. To reduce the delivered total voltage and energy, discharges with energy settings between 200 and 400 watt seconds should be avoided. If atrial fibrillation persists after a 200 watt second discharge one further attempt should be made with a 400 watt second charge and if unsuccessful the attempt should be abandoned. In this respect it is of interest that none of Oram and Davies' (1964) patients, requiring 400 watt seconds, converted to sinus rhythm. Reduction in the required energy levels can be achieved by moving the electrode from the left mid-axillary position to the left infrascapular area and by using large electrode pedals (Lown, 1964; Morris *et al.*, 1964).

It was noted by Cookson (1930) that the F wave in the electrocardiogram of patients with atrial fibrillation varied according to the ætiology of the arrhythmia. He found them "medium and large" in rheumatic heart disease, and "medium to small" in other types of heart disease. A more exact relation was shown by Skoulas and Horlick (1964) who found the F waves to be fine (< 0·5 mm.) in 70 per cent of 217 patients with ischæmic heart disease, and coarse (> 0·5 mm.) in 68 per cent of 96 patients with rheumatic heart disease. Aber (1962) examined the relation between the size of F waves and the success of quinidine conversion and found that it was more difficult to convert patients whose F waves were of small amplitude. However, all 13 patients in his study who did not convert had long-standing atrial fibrillation, a factor that affects the conversion rate, and no attempt was made to separate the effects of these two factors. Aber's (1962) observations were confirmed by Oram and Davies (1964). The writer was able to show that the size of F waves did significantly affect the success of conversion and that this correlation was independent of other influences. The small F waves or the absence of any fibrillatory activity on the electrocardiogram may represent a severe degree of atrial damage that makes establishing sinus rhythm more difficult.

Minor electrocardiographic abnormalities frequently occur after delivery of a direct current discharge. The more serious abnormalities of ventricular tachycardia and ventricular fibrillation were not encountered. Killip (1963) described a patient in whom direct current shock was followed by ventricular fibrillation on two occasions. It should be possible to avoid these arrhythmias by carefully checking the synchronization. The dangers of artefacts triggering the direct current discharge can be almost completely eliminated by decreasing the sensitivity of the synchronizer unit of the defibrillator until the largest electrocardiographic deflection just registers with the indicator.

Killip (1963) suggested that the occurrence of nodal rhythm and the failure of the sinus pacemaker to become established were due to the presence of a "dead" sinus node. He treated his patients with atropine to maintain an adequate ventricular rate and with alkalis and potassium depletion to re-establish atrial fibrillation. Atropine was also used in this study to increase the slow ventricular rate, and in some cases this measure alone was adequate in establishing sinus rhythm, while in other cases potassium administration had the same result. It seems that vagal hyperactivity, possibly due to digitalis, rather than the presence of a structurally abnormal sinus node, plays a large part in producing nodal rhythm.

It was shown that digitalis toxicity adversely affects the results of conversion, and it is therefore recommended that care should be taken to avoid digitalis overdosage in patients to be converted.

Lown *et al.* (1963) drew attention to the increased P-R interval in patients whose atrial fibrillation was abolished by direct current shock. That this corre-

lation exists was proven in this study: statistically highly significant differences were found between the converted patients and the controls. It is possible that either the disease process causing the atrial fibrillation or long-standing atrial fibrillation itself may damage the conducting systems of the heart, and that this leads to the production of grade I heart block when sinus rhythm is established. That this phenomenon is not due to the direct current shock is suggested by the persistence of prolonged P-R interval in most cases while sinus rhythm is maintained. This finding is of importance since the prolongation of the interval between atrial and ventricular systole diminishes the hæmodynamic improvement that occurs with the establishment of sinus rhythm. Brockman (1963) has shown that in dogs with artificially produced heart block improvements in aortic systolic pressure, in stroke volume, and in end-diastolic myocardial fibre length are maximal at an atrial systole—ventricular systole interval of 0·085–0·15 second. As this interval lengthens the effect of atrial systole diminishes.

In contrast with quinidine conversion direct current defibrillation was found to be not only an efficient but a remarkably safe method. Sudden death following quinidine administration is not a rarity. Thomson (1956) reported on 20 deaths among 671 patients treated. This danger was also emphasized by Askey (1946). Rokseth and Storstein (1963) described sudden loss of consciousness with respiratory and circulatory depression in 12 out of 274 patients. The conventional test dose is no help in this respect, since collapse may occur after small as well as large doses. If quinidine is to be used, and it is doubtful whether the effectiveness justifies the risks involved, continuous medical supervision is essential and cardiac monitoring advisable. In this study complications were few and after the only fatality the use of quinidine was abandoned.

The danger attached to establishment of sinus rhythm by any means is the dislodgement of emboli by atrial contractions. This risk is also present when atrial fibrillation is abolished by direct current shock. Anticoagulants have been used in an attempt to lessen the risk of embolization (Lown et al., 1963). Opinion remains divided as to whether or not prophylactic anticoagulation prior to conversion should be used. Killip (1963) found no difference in the incidence of embolism between two groups of patients where only one group was receiving anticoagulants. In this study, conversion of patients with significant mitral stenosis who were most likely to have atrial thrombi was postponed until after valvotomy when the left atrium was flushed clear of clots. Anticoagulants were not used and only one patient had an embolic episode.

The need for anæsthesia adds to the risks of direct current conversion. Stock (1963) suggests that anæsthesia is not required. He argues that since pain perception requires the activation of synaptic systems it is unlikely that a single stimulus of 2·5 milli-seconds would set these in operation. This argument is probably valid, since none of our patients complained of pain. However, in our experience energy levels greater than 100 watt seconds are certainly disturbing for the patient. All but one refused a second attempt without anæsthesia. By simplifying the anæsthetic technique to the safe methohexitone sodium alone, without gas, scoline, or intubation, and by restricting the duration of anæsthesia to less than 5 minutes, the risks involved were much reduced.

The difficulty in maintaining sinus rhythm after atrial fibrillation has been abolished is well shown in this study. It is likely that the number of patients reverting to atrial fibrillation will increase with the length of follow-up. There was evidence, however, that the rate of reversion is maximal over the first month and then slows down considerably: 42 per cent of patients were still in sinus rhythm after 9 months.

Quinidine sulphate and effervescent potassium have been used independently in an attempt to prevent recurrence of atrial fibrillation. There was no evidence that these drugs prolonged the duration of sinus rhythm when compared with a group of patients who had no prophylactic therapy. It seems that already existing atrial damage is the main factor in causing recurrence of atrial fibrillation. Exercise, emotion, and infection are known to be precipitating factors, but their full significance is still in doubt. The observation that some patients maintain sinus rhythm for considerably longer periods after the second than after the first conversion is of interest.

The present study indicates that direct current conversion of atrial fibrillation should be attempted, and is likely to be successful, in patients in whom the arrhythmia occurs following mitral valvotomy or other cardiac surgery, and when the arrhythmia persists after the treatment of thyrotoxicosis. Direct current conversion has also been found of value in the treatment of atrial fibrillation associated with ischæmic heart disease and in cases of idiopathic atrial fibrillation. In patients with severe rheumatic heart disease and multiple valvular involvement, conversion may be attempted, though the likelihood of success is smaller. Conversion has not been attempted in patients with unrelieved tight mitral stenosis because of the risk of pulmonary œdema and of systemic embolization. It has been found that severe predominant mitral regurgitation, gross

cardiac enlargement, atrial fibrillation of over 5 and particularly of over 10 years' duration, the absence of atrial fibrillatory waves, and possibly the presence of digitalis toxicity, mitigate against a successful conversion. None of these should, on their own, preclude an attempt at cardioversion, since once sinus rhythm is established it may persist for months. In patients where two or more of these factors operate, controlled atrial fibrillation may be preferred to sinus rhythm of short duration, possibly followed by uncontrolled atrial fibrillation. This latter complication was shown in this study to be detrimental, as it resulted in congestive heart failure in previously well-compensated patients. To avoid the danger of uncontrolled atrial fibrillation causing congestive heart failure, it may be advisable to keep all patients on a small dose of digitalis. This will prevent rapid ventricular rates should atrial fibrillation recur. Repeat conversions when attempted produced excellent results, even in patients who reverted to atrial fibrillation a few days after the first conversion. It is felt that a second attempt at abolishing atrial fibrillation is justified in most patients who relapse. Out-patient treatment of atrial fibrillation by direct current shock was found to be safe and particularly suitable for patients having their second conversion, though so far it has been performed in only a few instances.

SUMMARY

Direct current conversion was used in 175 patients in an attempt to abolish atrial fibrillation. This was successful in 137 (78%).

The complications associated with this method are minimal. It was found that the duration of atrial fibrillation, cardiomegaly, and the presence of small fibrillatory waves on the electrocardiogram adversely affected the success rate of conversion. Digitalis toxicity may also diminish the chances of successful conversion.

The questions of anticoagulation, of anæsthesia, and of out-patient treatment are discussed.

It is shown that neither quinidine nor potassium therapy diminish the chances of reversion to atrial fibrillation.

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