Indications and Contraindications for the Use of Molar Sodium Lactate

By Samuel Bellet, M.D. and Fred Wasserman, M.D.

The experience with molar sodium lactate has been extended to include 101 patients. Certain indications and relative contraindications to its use have crystallized. Administration of this agent is shown to be a physiologic and effective method for treating patients with severe hyperpotassemia, multiple Stokes-Adams attacks, and cardiac arrest, particularly that occurring in the operating room complicating cardiac surgery. For many patients in these categories, sodium lactate was life saving even though it was generally given after other more commonly used drugs and methods of therapy had proved ineffective in restoring cardiac rhythm. In the total group of patients untoward effects were few.

The initial work on the use of molar sodium lactate was reported from this laboratory in May, 1955,1 on the basis of a series of 6 cases. At that time its use was discussed in the following conditions: restoring cardiac beating during cardiac arrest in Stokes-Adams attacks and during episodes of cardiac arrest of other etiologies, and increasing the slow ventricular rates of sinus bradycardia and partial and complete A-V heart block. The rationale was based on an entirely different principle in therapy from that previously used in the human subject (e.g., atropine and sympathomimetic drugs). Its efficacy apparently depends upon an alteration in the electrolyte pattern in the extracellular fluid, which becomes more physiologic or tends to increase cardiac rhythmicity. Since this report, further communications2-4 amplified these initial observations, which included our preliminary impressions regarding the dose, route, and speed of administration, toxic effects, and possible modes of action. Subsequently, our experience has been extended to include a total of 101 patients. In these we have been able to study more completely the place of molar sodium lactate in the situations mentioned above and in addition have elaborated on 2 other conditions in which it has manifested salutory effects.

RESULTS

Table 1 summarizes the number of subjects in each of the different categories studied. For the sake of conciseness only the pertinent data in each category will be briefly discussed.

A. The data on the effects of molar sodium lactate in normal patients have been previously presented. No untoward effects were observed.5

B. Ten patients, ranging in age from 52 to 81 years, manifested clinical and electrocardiographic evidence of varying degrees of myocardial abnormality and myocardial damage (including partial A-V block). Untoward effects were observed in 4 patients and consisted of transient T-wave inversion (2 cases) and transient extrasystoles (2 cases).2,3 These effects were observed in older patients who presented a severe grade of myocardial damage; they were transient and persisted for only 1 or 2 minutes after cessation of the infusion. In the presence of partial A-V block (6 cases) the alterations in the atrial and ventricular rates were slight and insignificant in the doses given. The chief exception was observed in the presence of atrial fibrillation with slow ventricular rates ranging from 40 to 60 per minute (3 cases). In these patients the ventricular rate was significantly increased (by 10 to 40 beats per minute) following the infusion.

C. In 6 of 8 patients who had evidence of myocardial abnormality with sinus bradycardia there was a significant increase in the ventricu-
lar rate. Two instances of nodal escape were abolished as the ventricular rates increased. There was only a slight increase in the ventricular rate in the remaining 2 cases. No untoward effects were observed in this group.

D. These patients with asymptomatic complete A-V block ranged in age from 55 to 80 years, with an average of 66 years. Most of the patients manifested an advanced grade of arteriosclerosis. The atrial rhythm was of sinus origin in 14 and atrial fibrillation was present in 3 cases. In the 3 subjects with atrial fibrillation the ventricular rates increased from 32 to 38, 39 to 48, and 45 to 52 per minute, respec-

<table>
<thead>
<tr>
<th>Code</th>
<th>Type of cases</th>
<th>Number of cases previously reported</th>
<th>Total cases to date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Normal subjects</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>Myocardial damage (including partial A-V block)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>Sinus bradycardia</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>Asymptomatic complete A-V block</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>E</td>
<td>Stokes-Adams (ventricular standstill, ventricular flutter, and ventricular fibrillation)</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>F</td>
<td>Cardiac arrest during surgery</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>G</td>
<td>Terminal cardiac arrest</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>H</td>
<td>Hyperpotassemia of various etiologies</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>51</td>
<td>101</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of molar sodium lactate in a patient with complete A-V block and ventricular extrasystoles in the control tracing. A. Control tracing showing complete A-V block and frequent extrasystoles, some of which occur in groups of two and three. B. Continuous record, 4 minutes after 100 ml. of molar sodium lactate in 10 minutes, showing transient ventricular flutter and fibrillation. The patient died 12 hours later.
### Table 2.—Ten Patients* with Frequent Stokes-Adams Attacks

<table>
<thead>
<tr>
<th>Case no., age, and sex</th>
<th>No. of attacks</th>
<th>Other drugs used before molar sodium lactate</th>
<th>Results with other drugs</th>
<th>Molar Sodium Lactate</th>
<th>Ultimate fate</th>
<th>Results and remarks</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1 71 18 yrs.</td>
<td>About 100 in 18 hrs.</td>
<td>Neosynephrine, atropine</td>
<td>Progressive increase in frequency of seizures</td>
<td>360 ml. (15 molar) 1000 ml. (0.5 molar)</td>
<td>30 min. 3 hrs.</td>
<td>Died 18 hrs. after admission to hospital. Each episode characterized by ventricular standstill. Immediately following the SL the episodes ceased and the beating continued as long as the infusion was running. SL was successful on repeated trials.</td>
</tr>
<tr>
<td>2 75 yrs. daily for 10 days</td>
<td>Epinephrine in oil, ephedrine</td>
<td>Ineffective in controlling frequency of seizures</td>
<td>40-50 ml. i.v.</td>
<td>1-2 min.</td>
<td>Survived</td>
<td>Attacks of 2 types: standstill and ventricular tachycardia-flutter. MSL effective in both types.</td>
</tr>
<tr>
<td>3 68 yrs. day for 5 days</td>
<td>Epinephrine (in oil and aqueous), ephedrine, Isuprel</td>
<td>Ineffective in controlling seizures but frequency decreased</td>
<td>100 ml. i.v.</td>
<td>60 min.</td>
<td>Survived, left hospital with NSR</td>
<td>After MSL the normal sinus rhythm with RBBB appeared. After 6 weeks at home on oral MSL 100 ml. i.d., NSR still present.</td>
</tr>
<tr>
<td>4 65 yrs. 4 in 24 hrs.</td>
<td>Ephedrine, Isuprel</td>
<td>Ineffective</td>
<td>500 ml. (16 molar) i.v.</td>
<td>30 min.</td>
<td>Survived</td>
<td>Seizures ceased after MSL</td>
</tr>
<tr>
<td>5 83 yrs. 15 in 6 hrs.</td>
<td>Epinephrine, atropine, atropine</td>
<td>Ineffective</td>
<td>240 ml. i.v.</td>
<td>4 hrs.</td>
<td>Died 10 days later</td>
<td>Immediate restoration of cardiac beating and cessation of attacks. On a second trial 10 days later while on Isuprel, ephedrine, and atropine, MSL was ineffective and the patient died.</td>
</tr>
<tr>
<td>6 94 yrs. 40 in 1 hr.</td>
<td>Isuprel</td>
<td>Ineffective</td>
<td>1000 ml. i.v.</td>
<td>6 hrs.</td>
<td>Died 9 hours after admission to hospital</td>
<td>Mechanism of S-A seizures was ventricular tachycardia-flutter-fibrillation; MSL markedly decreased the frequency of these episodes but did not stop them. Responded best to combination of epinephrine and MSL by slow iv drip.</td>
</tr>
<tr>
<td>7 79 yrs. multiple</td>
<td>Epinephrine, atropine in oil, Metrazol</td>
<td>Ineffective</td>
<td>240 ml. i.v.</td>
<td>30 min.</td>
<td>Survived</td>
<td>This patient continued to have frequent S-A attacks while on an electric pacemaker. Spontaneous ventricular beating returned 30 min. following i.v. MSL and the patient was taken off the external electric pacemaker by 40 hrs. of continuous use.</td>
</tr>
<tr>
<td>8 65 yrs. 6-12 per hr.</td>
<td>Epinephrine</td>
<td>Ineffective</td>
<td>120 ml. i.v.</td>
<td>30 min.</td>
<td>Survived</td>
<td>MSL restored cardiac beating and terminated S-A attacks on repeated trials on different days. Return first degree A-V block.</td>
</tr>
<tr>
<td>9 71 yrs. 20 episodes in 4 hrs.</td>
<td>Norepinephrine to maintain blood pressure</td>
<td>Ineffective</td>
<td>120 ml. rapidly</td>
<td>4 hrs.</td>
<td>Survived</td>
<td>MSL stopped the episodes of ventricular standstill. There was a transient return to NSR for about 1 min. following which complete A-V block returned. No change in conduction on a second trial.</td>
</tr>
<tr>
<td>10 77 yrs. 6 in 2 hrs.</td>
<td>Epinephrine, norepinephrine</td>
<td>Effective in controlling the seizures</td>
<td>180 ml. i.v.</td>
<td>2 hrs.</td>
<td>Died 5 days after admission of unrelated disease</td>
<td>Decreased frequency and finally abolished episodes of ventricular standstill (longest one lasted 57 seconds).</td>
</tr>
</tbody>
</table>

* All these patients had arteriosclerotic cardiovascular disease; complete A-V block was the basic rhythm in every case, atrial fibrillation was present in case 10. An old myocardial infarction was present in case 2 and a subacute infarction in case 10.

S-A = Stokes-Adams.

ML = Molar sodium lactate; used unless otherwise indicated.

i.v. = Intravenous.

NSR = Normal sinus rhythm.

occurring within a short period of time (table 2); (2) 7 patients showed either isolated episodes of cardiac arrest occurring at longer intervals of time or a single attack of variable duration.

It is often difficult to evaluate the efficacy of a particular form of therapy for isolated Stokes-Adams seizures, since the episodes often spontaneously stop. The exact relationship, therefore, between the effect observed following molar sodium lactate in the second group of 7 patients, whether it was coincidental or a result of the drug, was more difficult to establish, since the Stokes-Adams attacks showed no definite pattern for comparison. For this reason we are not including the effect of sodium
lactate therapy in restoring cardiac beating in this group of patients.

In patients with repeated Stokes-Adams episodes occurring within the space of a few hours, particularly when they present a relatively uniform pattern, character and duration, the effect of intravenous drug therapy can be judged with much greater reliability. Molar sodium lactate was successful in the first group of 10 patients in restoring ventricular beating in 7 cases during many repeated trials (in the majority of cases 10 or more trials). With repeated episodes of ventricular standstill the rapid infusion of molar sodium lactate consistently restored ventricular beating. In 4 of these cases where electrocardiographic records are available the rate of the idioventricular pacemaker could be directly related to the rate of the intravenous infusion. As the rate of the infusion was speeded the idioventricular rate increased above the control rate; it subsequently slowed, on repeated trials, as the rate of the infusion was purposely slowed (fig. 2 and fig. 1 of reference 1). Table 2 summarizes the pertinent data on the 10 patients with multiple Stokes-Adams seizures occurring within a brief period of time. The average age of these patients was 75 years. Most patients (7) had received 2 or more frequently used agents for the treatment of Stokes-Adams attacks prior to the molar sodium lactate. The most commonly used drugs were sympathomimetic [epinephrine, phenylephrine (Neosynephrine), isopropylnorepinephrine (Isuprel), and ephedrine] and parasympatholytic agents (atropine).

In case 10 sympathomimetic agents temporarily stopped the Stokes-Adams seizures, and in case 6 the combination of sympathomimetic agents and molar sodium lactate appeared to be more effective than either drug alone. Restoration of ventricular beating after sodium lactate occurred in 2 patients (cases 2 and 6) in spite of episodes of ventricular flutter and fibrillation. Case 6 is particularly interesting in that the mechanism of all of the many Stokes-Adams seizures was paroxysmal ventricular tachycardia-flutter and fibrillation. The intravenous administration of molar sodium lactate markedly diminished the frequency of these paroxysms (fig. 3). In 2 instances (cases 5 and 6), however, the molar sodium lactate solution, although initially effective, ultimately failed to influence the episodes of cardiac standstill and death ensued.

Six of these 10 patients survived (cases 2–4, 7–9) and were ultimately discharged from the hospital. In 5 of the 6 the administration of molar sodium lactate was apparently life-saving. Other similar patients have been reported who responded to sodium lactate after sympathomimetic and vagolytic drugs had failed.5,6 Patient 7 continued to have episodes of ventricular standstill while on the artificial electric pacemaker and showed no signs over a 40-hour period of observation of spontaneous idioventricular beating. Thirty minutes after intravenous molar sodium lactate the pacemaker was discontinued and the spontaneous idioventricular beating continued; this patient was ultimately discharged from the hospital 6 weeks later. Curiously enough, none of these patients with multiple Stokes-Adams attacks in association with complete A-V block manifested extrasystoles, during the period of observation, even after large amounts of the drug.

F. Molar sodium lactate was used in 12 cases of cardiac arrest occurring during surgery. Surgery was performed for the following conditions: congenital heart disease (5 patients), calcific aortic stenosis (3 patients), mitral insufficiency (2 patients), mitral stenosis (1 patient), mitral insufficiency and mitral stenosis (1 patient). In some of these cases molar sodium lactate was effective in restoring the heart beat.
Fig. 3. Case 6 in table 2, aged 94, with arteriosclerotic heart disease. Effect of molar sodium lactate on repeated Stokes-Adams seizures due to ventricular tachycardia-flutter and fibrillation. A. Lead V₁ at 7:15 p.m., showing complete heart block and ventricular tachycardia-flutter, originating from different foci. The frequency of the paroxysms of ventricular tachycardia-flutter and syncope decreased markedly after 20 ml. of molar sodium lactate. B. Lead V₁ at 8:40 p.m. after 1 hour and 15 minutes without lactate, showing a run of ventricular tachycardia-flutter at X. At Y, are ventricular extrasystoles, which increased in frequency. C. Lead V₁ at 9:00 p.m. after approximately 50 ml. of molar sodium lactate was given in 5 minutes. Only 2 extrasystoles occur, marked X, a striking decrease compared with B. D. Lead II, a continuous tracing at 10:05 p.m. The patient received 20 ml. of sodium lactate from 8:55 to 9:15 p.m. The patient has received 50 ml. of isotonic sodium chloride from 9:20 to 10:05 p.m. At the first X during ventricular flutter 40 ml. of molar sodium lactate were given intravenously rapidly in 1 minute; 9 seconds later, at the next X, the ventricular flutter stopped and idioventricular rhythm returned. E. Lead V₁ at 10:15 p.m. There are no extrasystoles. The ventricular rate has slowed to approximately 35 per minute.

after other measures, including cardiac massage, electric defibrillation, and sympathomimetic drugs (epinephrine, Neosynephrine, and Isuprel), employed over a period of 10 to 15 minutes were ineffective. In this group of 12 patients, molar sodium lactate restored effective cardiac beating in 7 cases. One of them died 7 hours after resuscitation; another died 15 hours postoperatively, and a third died within 24 hours; 4 survived and were ultimately discharged from the hospital. Table 3 summarizes the pertinent data on the 7 patients in whom molar sodium lactate was apparently successful in resuscitating the heart.

Although the total number of cases presented above indicates a high percentage of survival, it does not represent an accurate percentage of the survival rate during surgery; there were other instances where molar sodium lactate was used unsuccessfully in conjunction with other resuscitative measures in the treatment of cardiac arrest during surgery.

G. The 20 cases of terminal cardiac arrest included patients dying from carcinomatosis, cerebrovascular accidents, acute myocardial infarction, and a number of other morbid states. In many of these patients no lasting resuscitation could have been achieved and, therefore oxygen and artificial respiration were not used. In others the time interval from cessation of cardiac beating to resuscitative attempts was so long that the chance of reviving the patient was gone. In the cases seen within 2 to 3 minutes following ventricular standstill, successful restoration of cardiac beating of variable duration was frequently encountered. Two such cases have been previously reported, in them the administration of sodium lactate, oxygen, and artificial respiration resulted in a gradual elevation of the blood pressure to normal levels, improvement in the skin color and a return of the electrocardiogram to a normal configuration. Our experience with terminal cardiac arrest suggests that where the cause of the arrest is a sudden process (independent of a chronic incurable disease), the administration of molar sodium lactate together with other resuscitative measures might resuscitate the heart, much as it has in the surgical group.

In the presence of cardiac arrest occurring during Stokes-Adams seizures and occurring terminally, the question often arises how the
sodium lactate reaches the heart. If the drug is given intravenously rapidly, within one-half to 1 minute after the arrest, a cardiac effect may be produced, particularly if artificial respiration has been instituted. The respiratory movements create negative pressure in the chest and thereby promote the return of blood to the heart. With longer periods of arrest the effect of the intravenous injection is less evident, even when given rapidly and in extremely large doses in conjunction with artificial respiration. In such instances one must resort to slow intracardiac injection.

*H.* Hyperpotassemia kills by its cardiotoxic effects. The usual electrocardiographic manifestations of severe potassium poisoning are a

**TABLE 3.—Seven Patients with Cardiac Arrest during Surgery and Cardiac Resuscitation with Molar Sodium Lactate**

<table>
<thead>
<tr>
<th>Case no., age, and sex</th>
<th>Diagnosis</th>
<th>Surgical approach</th>
<th>Other resuscitative measures</th>
<th>Molar sodium lactate</th>
<th>Ultimate fate</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 42♂</td>
<td>Interatrial septal defect</td>
<td>Direct vision with hypothermia</td>
<td>Atropine, adrenalin, electric defibrillation, manual compression</td>
<td>450 ml.</td>
<td>4 hrs.</td>
<td>Discharged from the hospital</td>
</tr>
<tr>
<td>2 53♀</td>
<td>Severe calcific aortic stenosis</td>
<td>Transaortic</td>
<td>Manual defibrillation, electric defibrillation, atropine</td>
<td>300 ml. iv 2700 ml. iv</td>
<td>20 min. 18 hrs.</td>
<td>Discharged from the hospital</td>
</tr>
<tr>
<td>3 29♀</td>
<td>Giant left atrium and severe mitral insufficiency</td>
<td>Left atrial</td>
<td>Electric defibrillation, noradrenaline, epinephrine, epinephrine, Isuprel</td>
<td>500 ml. iv</td>
<td>1½ hrs.</td>
<td>Died 7 hrs. postoperatively</td>
</tr>
<tr>
<td>4 11 mos. 3♂</td>
<td>Pulmonic stenosis with patent foramen ovale</td>
<td>Transventricular</td>
<td>Manual compression, atropine</td>
<td>30 ml. iv</td>
<td>20 min.</td>
<td>Discharged from the hospital</td>
</tr>
<tr>
<td>5 6 mos. 9♀</td>
<td>Ventricular septal defect</td>
<td>Open technique with pump-oxygenator</td>
<td>Manual compression, atropine</td>
<td>10 ml. iv</td>
<td>10 min.</td>
<td>Died 15 hrs. postoperatively</td>
</tr>
<tr>
<td>6 9 mos. 9♀</td>
<td>Pulmonic atresia and tetralogy of Fallot</td>
<td>Transventricular</td>
<td>Manual compression, atropine</td>
<td>10 ml. iv</td>
<td>5 min.</td>
<td>Died 24 hrs. postoperatively</td>
</tr>
<tr>
<td>7 42♀</td>
<td>Mitral stenosis</td>
<td>Left atrial</td>
<td>Manual compression, iv norepinephrine and Intracardial Methoxamine, calcium-chloride and procaine 2 per cent, electric defibrillation</td>
<td>250 ml. iv (.5 MSL) 40 ml.</td>
<td>10 min. 5 min.</td>
<td>Discharged from the hospital</td>
</tr>
</tbody>
</table>
slow idioventricular rhythm with widened QRS complexes and absent P waves; less frequently tachycardia is present. The hyperpotassemia in the 12 cases was of an advanced grade often associated with or secondary to uremia, with a concomitant shock-like state and characteristic electrocardiographic changes of advanced potassium intoxication. The serum potassemias ranged from 6.4 to 10.7 mEq per L. Molar sodium lactate had a prompt and salutory effect not only on the electrocardiographic but also on the circulatory changes. The clinical picture in almost all cases was vastly improved. The ultimate outcome of the patients was primarily determined by the extent and reversibility of the renal damage. Two of the 12 patients were discharged from the hospital; 2 were terminal on admission; and the remaining 8 patients lived from 15 hours to 30 days after treatment. In these 12 cases we have not encountered a single instance in which molar sodium lactate failed to improve or to reverse entirely the electrocardiographic changes due to potassium poisoning (figs. 4 and 6). Generally the clinical and electrocardiographic evidence of improvement appeared within 2 to 30 minutes following the infusion of molar sodium lactate. No extrasystoles were observed in the 12 cases; 2 anuric patients, however, developed pulmonary congestion after treatment with sodium lactate.

While most efficacious in acute potassium intoxication, the solution was also used for insidiously developing hyperpotassemia and acidosis. This group of patients is of particular importance since in them we have been able to prevent cardiac arrest as a cause of death with sodium lactate.

The electrocardiogram of the dying heart resembles that of hyperpotassemia. Reversal of the manifestations of depressed ventricular rhythmicity might explain some of the recoveries observed in the terminal cases as well

"Fig. 4. Effect of molar sodium lactate in hyperpotassemia in a 75-year-old patient with hypertension, nephrosclerosis, and uremia. A. Lead V3 at 9:00 p.m. There is a regular ventricular rate at 83 per minute, with QRS complexes widened to 0.14 second, and independent of the P waves. The serum K was 7.8 mEq./L. and no blood pressure was obtained. B. Lead V3 at 9:15 p.m. after 80 mEq. molar sodium lactate in 10 minutes. The blood pressure was 130/90. The ventricular rate is faster. The QRS complexes are narrowed to 0.10 second and the T waves are less tall. There is regular A-V conduction with a P-R of 0.22. C. Lead V3 at 9:17 p.m. after 90 mEq. sodium lactate in 12 minutes. The QRS complexes are 0.08 wide and the P-R interval is 0.20 second. D. Lead V3 at 9:19 p.m. after approximately 97 mEq. sodium lactate in 14 minutes. The ventricular rate is approximately 104 per min.; the P-R interval is 0.18 second. E. Lead V3R at 9:20 p.m. after 100 mEq. sodium lactate in 15 minutes. The blood pressure remained at 130/90; there was marked clinical improvement, and the sodium lactate was stopped."
INDICATIONS

as those in which anoxia resulted in a sudden increase in the extracellular potassium, which would also depress the cardiac pacemakers.

Discussion

Indications and Dosage of Molar Sodium Lactate

The experience to date suggests that molar sodium lactate is indicated in the following conditions:

A. Hyperpotassemia

Dosage. 1. In patients with electrocardiographic evidence of advanced potassium intoxication 100 ml. of molar sodium lactate was usually administered intravenously rapidly (in 1 to 2 minutes) followed by an intravenous infusion at a rate of approximately 30 to 60 drops per minute; the total amount given is dependent upon the effects observed; for example, in a reversion from a stage 3 or stage 4 (slow idioventricular rhythm with markedly aberrant ventricular complexes) to a stage 1 (tall, peaked T waves). 2. In patients with early electrocardiographic evidence of hyperkalemia, an intravenous infusion may be given at the rate of 15 to 30 drops per minute until the desired effects are observed.

B. Stokes-Adams Attacks

Since molar sodium lactate has a relatively short effect of about 2 hours it is not indicated unless the patient is having frequent, repeated episodes or, perhaps, at the precise time of a solitary attack. For the occasional or isolated Stokes-Adams episode long-acting sympathomimetic drugs are the preferred method of treatment. We have recently been using oral molar sodium lactate 90 ml. q.i.d. with promising results in an attempt to prevent or abort these occasional attacks.

Dosage. For multiple Stokes-Adams attacks, 40 to 80 ml. may be given intravenously in 1 to 2 minutes during an attack and may be followed by an intravenous infusion at the rate of 60 to 150 drops per minute, the exact rate and the total amount given being dependent upon the effects observed. As the ventricular rate increases the infusion should be slowed; when the pacemaker maintains a satisfactory rate and the episodes of cardiac arrest are abolished, the infusion should be stopped. From 240 ml. within 30 minutes to 1000 ml. in 6 hours have been given without untoward effects (table 2).

C. Cardiac Arrest During Surgery

The exact conditions under which sodium lactate is best employed for this condition requires further investigation.

Dosage. 1. When cardiac contractions are slow but effective or manual compression is
effective in maintaining adequate circulation, molar sodium lactate may be given intravenously at a rate of 100 to 200 drops per minute, approximately 7 to 14 ml. per minute. 2. In the presence of ventricular standstill or inefflectual manual compression or when the initial dosage of sodium lactate has not been effective, 20 to 40 ml. may be given slowly into the right ventricle at a rate of approximately 3 to 5 ml. per minute. 3. In infants, an intravenous infusion may be administered at a rate of approximately 1 ml. per minute while manual compression is continued.

D. Sudden Cardiac Arrest

The dose and route of administration of sodium lactate for these situations have not been ascertained. In a general way the schedule outlined for arrest during surgery should be followed.

Mechanism of Effects

The mechanism of action of molar sodium lactate in increasing cardiac rhythmicity is still under investigation. The following mechanisms were originally postulated: (a) the production of alkalosis increased the irritability of the myocardium, (b) the increase in the sodium raised the height of the action potential, (c) the lactate provided additional fuel for the heart, (d) a vagolytic effect increased the cardiac rate. Recently, we have suggested that one of the major factors is a decrease in the potassium in the extracellular fluid, which is accomplished by expansion of the extracellular space and movement of potassium intracellularly. A markedly increased rhythmicity of cardiac pacemakers by a low serum potassium has recently been documented in man and animals. A more favorable Na:K ratio is probably an additional factor. The effects on rhythmicity, while due chiefly to a variation in extracellular potassium, may be influenced indirectly by other electrolytes, e.g., sodium, calcium, and to a lesser degree, by magnesium.

Comparison of Sodium Lactate with Sodium Bicarbonate and Sodium Chloride

The original purpose of giving molar sodium lactate was to use a convenient, established, and relatively safe method of producing a mild grade of alkalosis. As far as we know, this principle was previously employed in the perfused heart, but has never been used in the intact animal or the human subject to increase cardiac rhythmicity. Substances with similar action may produce qualitatively similar effects (e.g., sodium bicarbonate), but sodium bicarbonate may be somewhat more toxic than sodium lactate, since it produces a marked shift in the pH quite rapidly. After our original observations we have studied the effect of sodium bicarbonate clinically and experimentally, for example, in hyperpotassemia in the nephrectomized dog; while the results are qualitatively similar, they are less marked with sodium bicarbonate and of shorter duration than with molar sodium lactate. Sodium chloride was even less effective than sodium bicarbonate. The chloride radical is a powerful anion, which tends to decrease the pH, thereby preventing or minimizing the decrease in extracellular potassium.

In summary, while similar in effect to sodium bicarbonate and sodium chloride, thus far molar sodium lactate would appear to be superior to them in the clinical states mentioned above.

Toxic Effects and Contraindications

Patients with complete A-V block are especially subject to develop ectopic rhythms because of areas of increased or decreased irritability in the heart muscle. The nodal or idioventricular pacemaker is notoriously unstable and any factor that increases cardiac work, such as the rapid infusion of fluid or hypertonic solutions (molar sodium lactate), might precipitate ectopic rhythms of various types. This is particularly likely when there are ectopic beats in the control tracing.

Extrasystoles are an important evidence of toxicity due to molar sodium lactate. They could result from the sudden increase in cardiac work or the lowering of serum potassium as a consequence of the production of or aggravation of alkalosis. Obviously, this toxic effect would tend to occur more commonly in the presence of established cardiac irritability, either latent or manifested by extrasystoles. In a general way, patients with severely diseased hearts...
and those with complete atrioventricular block belong in this category.

In early observations we showed that molar sodium lactate would increase cardiac rhythmicity in asymptomatic complete atrioventricular block.\(^1\) The ventricular rate increased in 9 patients of this type (53 per cent); however, extrasystoles were produced or were increased by molar sodium lactate in 5 subjects (29 per cent). We do not recommend molar sodium lactate for routine use in these cases of asymptomatic complete heart block, nor are sympathomimetic drugs routinely given to this group.

With the cessation of the infusion of molar sodium lactate the ectopic rhythm disappeared in a few seconds or minutes. It seems to us that this rapid cessation is less true of ventricular tachycardia resulting from the use of epi-

phrine or Isuprel; in these instances the effects are not easily reversible and ventricular fibrillation frequently ensues.

It is well documented that epinephrine may produce ventricular fibrillation, particularly in a damaged heart. Isuprel also tends to produce ventricular ectopic beats and ventricular fibrillation. Recently Zoll and co-workers\(^1\) stated, “epinephrine, norepinephrine, and isopropynorepinephrine differed only quantitatively . . . . Isopropynorepinephrine sometimes excited multifocal ventricular activity in the same dose required to arouse an idioventricular pacemaker; the effect on the blood pressure, if any, was a depressor one.”

The abolition or notable decrease of extrasystoles and of paroxysmal tachycardia after molar sodium lactate presents an interesting phenomenon. This was observed in 3 cases with extrasystoles (fig. 5) and in 2 subjects with paroxysmal supraventricular tachycardia associated with hyperpotassemia (fig. 6). While the mechanism in the latter group is more easily understandable, it is more difficult to explain the former. The following possibilities may be considered: (a) mild forms of hyperkalemia may have been unrecognized, (b) an increased ventricular rate resulting from the lactate may prevent discharge of ectopic foci, and (c) the lactate ion might improve cardiac function by acting as a fuel.

The presence of ventricular extrasystoles occurring in association with complete atrioventricular block presents a difficult therapeutic problem. Many of these patients have additional complicating factors: coronary artery disease with chronic or subacute myocardial infarction, congestive heart failure, electrolyte imbalance, or some other cause of cardiac irritability. Unless the extrasystoles are the result of a transient reversible factor, the prognosis in this group is poor, since they have an increased susceptibility to the development of ventricular tachycardia and ventricular fibrillation, leading to potentially fatal Stokes-Adams attacks. The use of quinidine or proca-

caine amide is contraindicated because, while these drugs may abolish the extrasystoles, they further depress already depressed ventricular pacemakers. Sympathomimetic drugs in the form of epinephrine or Isuprel are also dangerous because of their tendency to increase cardiac irritability, which may increase the rhythmicity of the idioventricular pacemaker, but in our experience has also increased the frequency of the ventricular premature contractions and caused runs of ventricular tachycardia.

In summary, the following circumstances either contraindicate the use of molar sodium lactate or indicate extreme caution in its use; (1) the appearance or increased frequency of extrasystoles following the administration of sodium lactate; (2) severe heart damage, particularly in association with overt or impending congestive heart failure; (3) hypokalemia or alkalosis.

**Summary**

Since our initial observations of the cardiovascular effects of molar and 0.50-molar sodium lactate, we have extended our experience to include 101 patients. Its value in certain clearly defined conditions has become apparent. In these sodium lactate has proved to be an extremely valuable addition to the therapeutic regimen.

Molar sodium lactate is shown to be a physiologic, safe, and rapid means of reversing the cardiotoxic manifestations of severe hyperpotassemia. The drug was successfully used in
10 patients with multiple Stokes-Adams seizures that occurred within a brief period of time, generally after sympathomimetic and vagolytic agents had been either totally ineffective or only partially effective. In addition, 12 cases of cardiac arrest occurring during intracardiac surgery were treated with molar sodium lactate within variable periods following the cardiac arrest—7 were successfully resuscitated for varying periods of time and 4 ultimately lived and were discharged from the hospital. In general, the usual therapeutic measures for cardiac arrest had been unsuccessfully tried prior to the administration of molar sodium lactate.

The presence of extrasystoles in the control tracing either contraindicates the use of sodium lactate or makes it mandatory that it be given with extreme caution under constant electrocardiographic control. An increase in pre-existing extrasystoles, short paroxysms of ventricular tachycardia, and the new development of extrasystoles have been observed. Congestive heart failure may also develop as another untoward effect of sodium lactate therapy.

Although qualitatively similar in its effects, molar sodium lactate was somewhat more effective over a longer period of time than sodium bicarbonate.

Preliminary comparisons with epinephrine and Isuprel have suggested that molar sodium lactate manifests less profibrillatory qualities when used in comparable effective doses under similar conditions. Because its action is based on a different principle from that of the vagolytic and sympathomimetic drugs, it may supplement these agents, and may also be effective in conditions where the others are entirely useless.

**Summario in Interlingua**

Depost nostre observationes initial in re le effectos cardiovasculare de lactato de natrium in solutiones de 1 o 0,5 M, nos ha extendite nostre experiencie a un serie total de 101 patientes. Le valor del medication in certe clarmente definite conditiones es nunc evidente. In iste conditiones, lactato de natrium se ha revelate como un utilissime addition al regime therapeutic.

Molar lactato de natrium es un medio physiologic, salve, e rapide pro reverter le manifestationes cardiotoxic de sever hyperkaliemia. Le droga eseva usate con successo in 10 patientes con multiple attacos de Stokes-Adams occurrente intra un breve periodo de tempore, generalmente post que agentes sympathomimetic e vagolytic se habeva monstrate totalmente inefficace o solmente partialmente efficace. In plus, 12 casos de arresto cardiac occurrente durante operationes intracardiac esseva tractate con molar lactato de natrium intra variabile periodos post le arresto. Septe del patientes esseva resuscitate pro varie periodos de tempore, e 4 superviveva e quitava le hospital. In general, le usual mesuras therapeutic pro arresto cardiac habeva esseva probate sin successo ante le administration de molar lactato de natrium.

Le presentia de extrasystoles in le electrocardiogramma preliminari es un contraindicacion del uso de lactato de natrium o al minus establi le necessitate de administrar le droga con alte grados de previdentia e sub le constante supervigilantia de observationes electrocardiographic. Augmento de pre-existente extrasystoles, breve paroxysmos de tachycardia ventricular, e le nove disveloppamento de extrasystoles ha esseva observate. Congestive disfallimento cardiac es etiam un possibile effecto adverse de therapia a lactato de natrium. Ben que le effectos de molar lactato de natrium esseva simile in qualitate al effectos de bicarbonato de natrium, le prime de iste medicationes esseva alicie plus efficace post prolongate periodos de tempore.

Comparationes preliminari con epinephrina e Isuprel suggere que in doses de comparabile efficacia e administrate sub comparabile conditiones, lactato de natrium es minus profibrillatori. Proque le principio de su action differe ab illo del action de drogas vagolytic e sympathomimetic, illo pote esser usate como supplemento de iste drogas e pote esser efficace in conditiones ubi illos es completely inutile.

**Acknowledgment**

The authors wish to thank Drs. Seymour Schotz and Robert P. Glover of the Presbyterian Hospital,
Dr. Rachel Ash of the Children's Hospital, and Dr. Francis C. Wood of the Hospital of the University of Pennsylvania for permission to report cases on their respective services.

REFERENCES


16 Ringer, S.: A further contribution regarding the influence of the different constituents of the blood on the contraction of the heart. J. Physiol. 4: 222, 1883.


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Circulation. 1957;15:591-602
doi: 10.1161/01.CIR.15.4.591
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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