"SMART" INFUSION APPARATUS FOR COMPUTATION AND AUTOMATED DELIVERY OF LOADING, TAPERING, AND MAINTENANCE INFUSION REGIMENS OF LIDOCAINE, PROCAINAMIDE, AND THEOPHYLLINE

William F. Nicholson and Roger W. Jelliffe

Laboratory of Applied Pharmacokinetics, USC School of Medicine
Los Angeles, California

Abstract

"Smart" infusion apparatus now computes loading and tapering infusion protocols to achieve and maintain chosen serum lidocaine levels for patients, using a 2-compartment model of lidocaine. The apparatus, an HP-41CV hand calculator with appropriate interface, delivers the regimen automatically, starting up and controlling an IVAC Model 1500 volumetric infusion pump with its IVAC computer interface module. The device appears capable of similar computation and automated administration of many other drugs such as procainamide and theophylline. Preliminary upward adjustments of the regimen can also be made in the apparatus now, without recourse to an external computer.

Introduction

Many intravenous drugs require both an initial loading infusion followed by a subsequent maintenance infusion. Examples are procainamide and theophylline. Still others, such as lidocaine, require a more complex protocol of an initial loading infusion, a tapering infusion protocol during the distribution phase of the drug, and then a final maintenance infusion. Clinicians have not been able to give such regimens easily, though, because it has often been difficult to make the required adjustments of the regimen at the precise stated times, and it is potentially dangerous if this is not done correctly.

A "smart" infusion device would improve this situation greatly. Such a smart device should be able by itself, 1) to communicate with other devices for sending and receiving data; 2) to deliver infusion protocols automatically; 3) to alert ward personnel to ongoing patient needs - the need to obtain a blood sample at a specific optimum time for therapeutic drug monitoring, or to change an IV bottle; 4) to display information such as the fluid infusion rate, the volume infused, the infusion rate of the drug itself, and the total amount of drug infused; 5) to calculate and adjust drug dosage regimens based on individual patient characteristics; 6) to adjust the infusion protocol in response to changing patient requirements or revised therapeutic goals.

A "Smart" Infusion Device

Our laboratory initially developed an early version of such a smart pump which delivered the tapering lidocaine regimens referred to above. It consisted of an IVAC Model 630 volumetric pump modified for control by an HP-41CV hand calculator with a clock function and a magnetic card reader. It would also be temporarily interfaced to a time-shared computer terminal. In that embodiment, the user first ran a time-shared clinical computer program to develop a tapering lidocaine infusion regimen individualized for that patient. The regimen was downloaded either directly into the smart pump or was transmitted to it by a magnetic card generated by another HP-41 connected to the time-shared computer terminal. The smart pump then started and delivered the regimen. It was battery powered and portable, for easy hospital or field use. In addition, the magnetic cards could form a pre-programmed library of regimens for use by paramedical personnel in the field.

Application of the Superposition Principle

In the past, when the patient's initial response to a chosen serum level was not satisfactory, the time-shared program was run again. Past lidocaine therapy was entered, the new serum level goal was chosen, and the new tapering regimen was developed to take the patient's serum level from the old value to the new desired value and to maintain that new value thereafter. The new adjusted regimen could be downloaded into the smart pump again and automatically delivered.

However, in most clinical situations, the above drugs can be described as linear time-invariant multicompartment systems. Because of this, the superposition principle for linear systems can be used to adjust therapy with such drugs for kinetically stable patients. The superposition principle permits upward adjustment of serum level goals at any later time simply by superimposing a certain percent of the initial protocol upon itself, starting at the desired time. Because of this, there is now no need to return to the time-shared computer. These clinically important adjustments can now be performed within the smart apparatus itself.
This principle was implemented for delivering tapering regimens of lidocaine. An initial time-shared computer program developed the initial individualized regimen and downloaded it into the HP-41CV programmable hand calculator. The apparatus then started up the pump and automatically delivered the initial regimen. The calculator, employing the superposition principle, made upward adjustments of therapy by itself, superimposing a desired fraction of the original protocol upon itself, without any further aid from the time-shared computer. Use of this principle has increased the ease and utility of delivering these individualized automated lidocaine regimens. The principle is applicable to many other drugs as well.

**Computation of the Initial Regimen by the Device**

The apparatus has now been further improved to permit computation of the initial lidocaine regimen by the device itself, adjusted to body weight and estimated cardiac function of the patient, to achieve and maintain the initial target serum level goal. This "smart" infusion apparatus not only makes it possible to deliver complex tapering infusion regimens which heretofore have been difficult or impossible to perform, but it is now capable of doing so without any initial assistance from the time-shared computer. In addition, preliminary adjustments of therapy for kinetically stable patients can also be made within the apparatus itself. Only when the patient's pharmacokinetic values appear to change, based on clinical information, or when serum level data become available for computation of the patient's individual parameter values, is the time-shared computer now needed.

This "smart" infusion apparatus, together with a book of programmable cards embodying software for average values of pharmacokinetic parameters for various drugs in various types of patients, should significantly enhance the precision, reliability, and safety of intravenous therapy with many drugs. Its battery power and portability permit easy use in the field by paramedical personnel in ambulances, as well as in the emergency room, intensive care unit, or coronary care unit. Information concerning the patient and his infusion regimen can then be passed on to other similar apparatus as the patient is transferred from the ambulance to the emergency room or from the emergency room to the ICU or CCU, by means of the magnetic card, which can now provide a record of the past therapy the patient received by the personnel employing the previous pump. This data can easily be entered into the next pump, the regimen can be reviewed, clinical goals evaluated, and either the same or a new adjusted regimen can once again be developed and automatically delivered. In addition, the magnetic card can be downloaded into a timeshared computer terminal as a useful and precise record of past therapy received.

**References**

