Hemodialysis Machines
Testing Your Understanding

NANT – Dialysis Boot Camp
Wednesday – March 18th, 2015
Las Vegas, Nevada
John Sweeney
In the early days of dialysis, the initial dialysis apparatus were one of a kind devices created by the doctor primarily to study and begin to understand how to treat ESRD. With the development of cannula to allow long term care, the need for mass production of equipment became a reality. Which company produced the first single patient fixed proportioning hemodialysis machine in the United States?

• A) Drake Willock
• B) Gambro
• C) Milton Roy
• D) Travenol Laboratories
• E) Baxter
History – First Proportioning Machine

- C) Milton Roy Company – The Model A in 1964
- It featured:
  - Hot water disinfection at 85 °C
  - Diode logic (Automated start-up and shut-down)
  - Variable Sodium
  - Alarm testing prior to treatment
  - Stainless steel plumbing
  - Patient remote control
  - Wood veneer for that “furniture” look
- Price - $7,200.00
Milton Roy Model A
Company History

There are a variety of companies making hemodialysis machines. Almost all of them started as pharmacies and evolved from there. Do you know your company’s history? Try this matching game:

• 1) Baxter
• 2) B. Braun
• 3) Fresenius
• 4) Gambro
• 5) Hospal

• A) Oldest company
• B) 1st balance chambers
• C) 1st synthetic membrane
• D) 1st production dialyzer
• E) 1st dry bicarb proportioning
# Oldest Company (2-A)

<table>
<thead>
<tr>
<th>Company</th>
<th>Year</th>
<th>Founder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baxter Healthcare</td>
<td>October 19(^{\text{th}}), 1931</td>
<td>Don Baxter/Ralph Falk</td>
</tr>
<tr>
<td>B. Braun Medical</td>
<td>June 23(^{\text{rd}}), 1839</td>
<td>Julius Wilhelm Braun*</td>
</tr>
<tr>
<td>Fresenius Medical; Care</td>
<td>October 1(^{\text{st}}), 1912</td>
<td>Dr. Eduard Fresenius</td>
</tr>
<tr>
<td>Gambro</td>
<td>1964</td>
<td>Nils Alwall/Holger Crafoord</td>
</tr>
</tbody>
</table>

Other company’s founding dates include Cobe Laboratories – 1964, Drake Willock – 1964, Hospal - 1977

* The “B” in B. Braun comes from Braun’s son, Bernhard
A Series of Firsts

• 1\textsuperscript{st} balance chambers (3 – B)
  • Fresenius – A 2008 C - 1979
• 1\textsuperscript{st} synthetic membrane (5 – C)
  • Hospal – AN69 - 1971
• 1\textsuperscript{st} production dialyzer (1 – D)
  • Baxter (Travenol Labs) – U 200 – 1956
• 1\textsuperscript{st} dry bicarb proportioning (4 – E)
  • Gambro – BiCart - 1987
AN69® Membranes – the most significant contribution to the quality of care of hemodialysis patients. More than ever, the “State of the Art”. The FILTRAL™ SERIES has been designed to accommodate any treatment strategy required of patients.
Heat Disinfection

• Dialysis machines using chemical disinfectants have not been fully successful in preventing the buildup of precipitation and bio-slime in their fluid pathways. Heat disinfection has proven to be more successful. Which of the following combinations of time and temperature will result in adequate disinfection?

• A) 80°C for 60 minutes
• B) 85°C for 45 minutes
• C) 90°C for 30 minutes
• D) 95°C for 20 minutes
Killing Bacteria = Time x Temperature

• The formula to ensure bacteria are killed is:

\[ A_o = 10 \left( \frac{T - 80^\circ C}{Z} \right) \times \Delta T \]

Where:  \( A_o = \) kill factor = 3000 for bacteria in water

\( Z = \) value varies by bacteria type. Use 10 if unknown

\( T = \) water temperature (°C)

\( \Delta T = \) Time at fixed temperature (seconds)

• The kill factor needs to be 5 to 10 times greater than 3000 to kill bacteria on system surfaces
Killing Times vs. Temperature

Green = no kill,  Red = water kill,  Blue = min biofilm kill,  Black = max. biofilm kill
(80°C for 60 minutes = 3600)

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>5 min</th>
<th>10 min</th>
<th>20 min</th>
<th>30 min</th>
<th>45 min</th>
<th>60 min</th>
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</thead>
<tbody>
<tr>
<td>85</td>
<td>949</td>
<td>1897</td>
<td>3795</td>
<td>5692</td>
<td>8538</td>
<td>11384</td>
</tr>
<tr>
<td>86</td>
<td>1194</td>
<td>2389</td>
<td>4777</td>
<td>7166</td>
<td>10749</td>
<td>14332</td>
</tr>
<tr>
<td>87</td>
<td>1504</td>
<td>3007</td>
<td>6014</td>
<td>9021</td>
<td>13532</td>
<td>18043</td>
</tr>
<tr>
<td>88</td>
<td>1893</td>
<td>3786</td>
<td>7571</td>
<td>11357</td>
<td>17036</td>
<td>22714</td>
</tr>
<tr>
<td>89</td>
<td>2383</td>
<td>4766</td>
<td>9532</td>
<td>14298</td>
<td>21447</td>
<td>28596</td>
</tr>
<tr>
<td>90</td>
<td>3000</td>
<td>6000</td>
<td>12000</td>
<td>18000</td>
<td>27000</td>
<td>36000</td>
</tr>
<tr>
<td>91</td>
<td>3777</td>
<td>7554</td>
<td>15107</td>
<td>22661</td>
<td>33991</td>
<td>45321</td>
</tr>
<tr>
<td>92</td>
<td>4755</td>
<td>9509</td>
<td>19019</td>
<td>28528</td>
<td>42792</td>
<td>57056</td>
</tr>
<tr>
<td>93</td>
<td>5986</td>
<td>11972</td>
<td>23943</td>
<td>35915</td>
<td>53872</td>
<td>71829</td>
</tr>
<tr>
<td>94</td>
<td>7536</td>
<td>15071</td>
<td>30143</td>
<td>45214</td>
<td>67821</td>
<td>90428</td>
</tr>
<tr>
<td>95</td>
<td>9487</td>
<td>18974</td>
<td>37947</td>
<td>56921</td>
<td>85381</td>
<td>113842</td>
</tr>
</tbody>
</table>

The Answer is D – 95°C @ 20 minutes
Dialysate Conductivity

• The standard way that a machine checks to ensure the proper mixture of concentrate and water is to measure the dialysate’s ability to conduct electricity. Dialysate consists of a variety of individual ions that contribute to the final total conductivity. If a dialysate prescription is changed to yield a higher bicarbonate level while keeping the Sodium constant the conductivity displayed by the machine should:

  A) remain unchanged since the Sodium is still the same
  B) increase because there is more bicarbonate
  C) decrease because there is less chloride
  D) Depends on how the machine is calibrated
## Conductivity Calculation

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>(#1) Conductance Factor</th>
<th>(#2) Charge mEq/L</th>
<th>(#3) Multiply #1 x #2</th>
<th>Divide #3 by 1000 Conductivity mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>104.178</td>
<td>100.00</td>
<td>10,418</td>
<td>10.418</td>
</tr>
<tr>
<td>KCl</td>
<td>126.185</td>
<td>2.00</td>
<td>252.4</td>
<td>0.252</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>102.810</td>
<td>2.50</td>
<td>257.0</td>
<td>0.257</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>105.973</td>
<td>0.75</td>
<td>79.5</td>
<td>0.080</td>
</tr>
<tr>
<td>NaC₂H₃O₂</td>
<td>69.829</td>
<td>4.00</td>
<td>279.3</td>
<td>0.279</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>73.464</td>
<td>33.00</td>
<td>2,424.3</td>
<td>2.424</td>
</tr>
<tr>
<td><strong>Total positive charges = Total negative charges</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>13.710</strong></td>
</tr>
</tbody>
</table>
The Case of the Increasing Bicarbonate

Bath fixed components: Ca$^{++}$ (1.5 mmol/L), K$^+$ (2 mmol/L), Mg$^{++}$ (0.5 mmol/L), CH$_3$COO$^{-}$ (3.0 mmol/L), C$_6$H$_{12}$O$_6$ (8.33 mmol/L)

Conductance factors: NaCl = 104.17, NaHCO$_3$ = 73.46

<table>
<thead>
<tr>
<th>Bicarb (mEq/L)</th>
<th>30.0</th>
<th>31.0</th>
<th>32.0</th>
<th>33.0</th>
<th>34.0</th>
<th>35.0</th>
<th>36.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride (mEq/L)</td>
<td>110.0</td>
<td>109.0</td>
<td>108.0</td>
<td>107.0</td>
<td>106.0</td>
<td>105.0</td>
<td>104.0</td>
</tr>
<tr>
<td>Conductivity (mS/cm)</td>
<td>13.87</td>
<td>13.84</td>
<td>13.81</td>
<td>13.78</td>
<td>13.74</td>
<td>13.71</td>
<td>13.68</td>
</tr>
</tbody>
</table>

Correct Answer: C) decrease because there is less chloride
Thinking Cost of Use

• Nothing comes cheap these days. The average cost of a kilowatt-hour of electricity in the United States is $0.13. With that in mind, about how much does it cost to operate a dialysis machine 16 hours a day, six days a week for an entire year?

• A) $100.00
• B) $250.00
• C) $500.00
• D) $1000.00
• Watt is the unit of energy in the metric system
• 1 watt (w) = 1 volt x 1 ampere
• 1 kilowatt (kW)= 120 volts x 8.33 ampere
• 1 kilowatt – hour (kWh) = 860,420.7 calories
• 1 calorie = energy to raise 1 mL of water 1°C
• A 100 watt light bulb burning for 10 hours = 1 kWh = $0.13
• The average household in the US used 10,837 kWh in 2012
• That’s 903 kWh/month x $0.13 = $117.39
Figuring the Cost

• Assume:
  • Water temperature to the machine is 25 °C (77°F)
  • Daily treatment time is 12 hours
  • Disinfect time is 4 hours
  • Disinfect = 300 mL/min @ 85°C
• Two scenarios:
  • Dialysate flow = 500 mL/min @ 37°C
  • Dialysate flow = 800 mL/min @ 37°C
Heating dialysate

- 500 mL/min @ 37°C = 30,000 mL/h
- Temperature change = 12 °C
- Calories = 30,000 x 12 = 360k/h
  - 360k calories = 0.418 kWh/h
  - 0.418 kWh x $0.13 = $0.054/h
  - 312 days x 12 h/day x $0.054/h = $203.30

- 800 mL/min @ 37°C = 48,000 mL/h
- Temperature change = 12 °C
- Calories = 48,000 x 12 = 516k/h
  - 516k calories = 0.600 kWh/h
  - 0.600 kWh x $0.13 = $0.078/h
  - 312 days x 12 h/day x $0.078/h = $292.03
Final Figures

• Yearly cost to disinfect 300 mL/min @ 85 °C for 312 days at 4 hours/day = $202.18 (based on 1,255 W)

• Actual Disinfect Wattage
  • Gambro Phoenix = 1,840 W ($296.42)
  • Gambro AK200 = 1,650 W ($265.81)
  • Fresenius 2008T = 1,500 W ($241.65)

• Add 0.250 kWh/h for pumps, electronics, monitor, etc. for 312 days at 16 hours/day = $162.24

• Final Cost:
  • 500 mL/min: $203.30 + $202.18 + $162.24 = $567.72
  • 800 mL/min: $292.03 + $202.18 + $162.24 = $656.45

• The correct answer is C) $500.00
Urea Monitoring

• If the urea clearing the dialyzer could be measured during a treatment, the true Kt/V could be known instead of being approximated. In recent years, methods have been developed and incorporated into the latest dialysis machines improving our ability to provide a better treatment for the patient. What are these technologies and their benefits?

Urea Monitoring via Conductivity – Fresenius Medical Care - OCM®, Gambro - DIASCAN®

• Utilizes the fact that diffusion rates for urea and Sodium Chloride are similar. (Sodium Chloride = 58.5, Urea = 60.0)

• Monitors dialysate conductivity pre and post dialyzer for differences due to blood interaction.

• Temporarily increases dialysate Sodium slightly at 20 minute intervals during treatment.

• Compares dialysate conductivity difference following the change with prior readings.

• The conductivity change will be in proportion to the urea clearance.
On-Line Clearance Method

Conductivity cell #1 measures dialysate conductance.

Conductivity cell #2 measures effluent conductance.

The conductivity difference is directly proportional to urea clearance.
On-Line Na\(^+\) Clearance Results

• Provides information on \textit{effective} clearance.
  • Vs. dialyzer manufacturer’s claims
  • New vs. reused dialyzer actual performance
  • Detection of technical problems (\textit{but not identification of specific problem})
    • ex. High pre-pump arterial pressure, inaccurate blood pump setting, error in pump calibration, inadequate \(Q_D\), dialyzer clotting, etc.

• With multiple sampling during dialysis, can predict treatment outcome.
  • Enables adjustment of treatment parameters, prn
  • Dialysis efficiency can be documented every run
# On-Line Na⁺ Clearance

<table>
<thead>
<tr>
<th><strong>Advantages</strong>¹</th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Accuracy equivalent to Daugirdas-Schneditz urea method</td>
<td>• Does not measure urea, thus no:</td>
</tr>
<tr>
<td>• No blood or dialysate sampling</td>
<td></td>
</tr>
<tr>
<td>• No lab costs</td>
<td></td>
</tr>
<tr>
<td>• No staff time, effort</td>
<td></td>
</tr>
<tr>
<td>• Real time results enable intervention</td>
<td>• Small risk of excess sodium exposure</td>
</tr>
<tr>
<td></td>
<td>• Small additional equipment cost</td>
</tr>
</tbody>
</table>

Urea Monitoring using UV Absorption - B. Braun - Adimea® Urea Monitor

• Measures dialysis efficiency by determining the reduction in molar concentration of urinary excreted substances in the spent dialysate.
• A UV light source shines light through the effluent coming from the dialyzer.
• Particles in the effluent absorb the UV light reducing the amount that reaches the UV sensor diametrically across from the light source.
• The reduction in light is in direct proportion to the amount of excreted substances from the patient.
• Urea is the key ingredient
Urea Monitoring using UV Absorption

1 – Ultraviolet light source
2 – Waste products from the patient
3 – Ultraviolet light detector
Urea Monitoring using UV Absorption

• Adimea® provides an accurate measurement process for reliable and continuous control of the dialysis dose (Kt/V) throughout the entire treatment. Treatment parameters can be adjusted by doctors and nursing staff for the benefit of patients even during treatment. This allows the equipment to optimally support the execution of the treatment objectives.

• The UV absorption measurements can be used for determining the dialysis dose as there is a very close linear correlation between the measured UV absorption signal and the urea in the dialysate.

Uhlin F, Fridolin I, Magnusson M, Linberg L-G. Dialysis dose (Kt/V) and clearance variation sensitivity using measurement of ultraviolet absorbance (on-line), blood urea, dialysate urea and ionic dialysance. Nephrol Dial Transplant (2006) 21: 2225-2231
Urea Monitoring using UV Absorption - Benefits

• Monitoring of the effluent for substances coming from the patient is continuous
• No determination of V – merely requires the pre-dialysis weight
• Configurable and clear display of URR, spKt/V, eKt/V as well as result prognosis
• Changes to treatment parameters possible at any time
• Notification if expected URR will not be reached
Final Question!

- This question relates to chemistry. Identify the following chemical formulas. Hint: Two of them are jokes and the third is a real substance.

\[ \text{Fe}^{++} \quad \text{Fe}^{++} \quad \text{Fe}^{++} \quad \text{Fe}^{++} \]

\[ (\text{C}_{27}\text{H}_{22}\text{O}_{4}\text{S})_n \]

\[ \text{N}\quad \text{H} \quad \text{H} \]
Final Answers!

- Ferrous Wheel
- Polysulphone
- Amino World

$\text{(C}_{27}\text{H}_{22}\text{O}_{4}\text{S})_n}$