I. Bioelectrical impedance applied to HD and PD
II. Bioimpedance measurements in HD patients and relation with clinical state
III. Segmental and whole-body bioimpedance measurements in CAPD
IV. Acknowledgments
I. Bioelectrical impedance applied to HD and PD

...the chronic renal insufficiency (CRI) represents one of the main problems of public health of this century ........

....the cost of the renal insufficiency treatment, by means of dialysis or renal transplant, is between 15,000 € and 30,000 € per person per year.....

.....approximately 500 million people in the world suffer renal disease......

....the chronic renal insufficiency between the 10 first causes of death in the world!!!

Approximately one of each ten citizens lives with renal disease, number that will be increasing in the future!!!!!!!
I. Bioelectrical impedance applied to HD and PD

- **Electrode positions**

1. Distal BIA  
   *(Lukaski, 1986)*

2. Proximal BIA  
   *(Lukaski and Scheltinga, 1994)*
I. Bioelectrical impedance applied to HD and PD

- **Electrode positions**

3. Segmental BIA
   
## I. Bioelectrical impedance applied to HD and PD

### Conventional bioelectrical impedance methods

#### 1. Regression equations (monofrequency, 50 kHz)

<table>
<thead>
<tr>
<th>Study</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kushner et al 1986</td>
<td>$TBW = 0.556 \frac{H^2}{R} + 0.095 \text{Wt} + 1.726$</td>
</tr>
<tr>
<td>Kushner et al 1992</td>
<td>$TBW = 0.590 \frac{H^2}{R} + 0.065 \text{Wt} + 0.040$</td>
</tr>
<tr>
<td>Lukaski et al 1988</td>
<td>$TBW = 0.377 \frac{H^2}{R} + 0.140 \text{Wt} - 0.080 \text{year} + 2.90 \text{gender} + 4.65$</td>
</tr>
<tr>
<td>Lukaski et al 1986</td>
<td>$FFM = 0.756 \frac{H^2}{R} + 0.110 \text{Wt} + 0.107 \text{Xc} - 5.463$</td>
</tr>
<tr>
<td>Gray et al 1989</td>
<td>$FFM = 0.00108 \frac{H^2}{R} - 0.02090 R + 0.23199 \text{Wt} - 0.06777 \text{year} + 14.59753, \text{Female}$</td>
</tr>
<tr>
<td></td>
<td>$FFM = 0.00132 \frac{H^2}{R} - 0.04394 R + 0.30520 \text{Wt} - 0.16760 \text{year} + 22.66827, \text{Male}$</td>
</tr>
<tr>
<td>Heitman et al 1990</td>
<td>$FFM = 0.279 \frac{H^2}{R} + 0.181 \text{Wt} + 0.231 \text{H} + 0.064 \text{gender} \text{Wt} - 0.0777 \text{year} - 14.94$</td>
</tr>
<tr>
<td>Deurenberg 1991-b</td>
<td>$FFM = 0.34 \times 10^4 \frac{H^2(m)}{R} + 15.34 \text{H} - 0.273 \text{Wt} - 0.127 \text{year} + 4.56 \text{gender} - 12.44$</td>
</tr>
<tr>
<td>Stolarczyk et al 1994</td>
<td>$FFM = 0.001254 \frac{H^2}{R} - 0.04904 R + 0.1555 \text{Wt} + 0.1417 \text{Xc} - 0.0833 \text{year} + 20.05$</td>
</tr>
</tbody>
</table>
I. Bioelectrical impedance applied to HD and PD

- Conventional bioelectrical impedance methods

2. Cole-Cole model (multifrequency)

\[
Z = R_\infty + \frac{(R_0 - R_\infty)}{1 + (j\omega\tau_z)^\alpha}
\]

Cole 1940

Wessel diagram
I. Bioelectrical impedance applied to HD and PD

- Conventional bioelectrical impedance methods

3. Bioelectrical Impedance Vector Analysis, BIVA (50 kHz)

Univariate and bivariate the tolerance interval
I. Bioelectrical impedance applied to HD and PD

- Conventional bioelectrical impedance methods

3. Bioelectrical Impedance Vector Analysis, BIVA (50 kHz)

RXc-graph, Piccoli (1994)
I. Bioelectrical impedance applied to HD and PD

- Conventional bioelectrical impedance methods

3. Bioelectrical Impedance Vector Analysis, BIVA (50 kHz)

Z-score, Piccoli (2002)
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Subject and Methods

Service of Nephrology, Provincial University Hospital, Santiago de Cuba

To demonstrate the usefulness of the bioimpedance techniques (mono and multifrequency) to classify patients by their hydration and nutrition state.

- 74 patients/ BHD and AHD
- Stable (without oedema) or critical (hyper-hydrated, with oedema and malnutrition) by clinical inspection.

BIOSCAN: BL–960141
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Subject and Methods

Student’s t test
Hotelling’s T2 test

- BHD: 74 (46 stable, 28 critical)
- AHD: 40 patients (21 stable, 19 critical)
III. Bioimpedance measurements in HD patients and relation with clinical state

✅ Results

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

42 patients (26: M-16 F, 30-60 yr, 1.50-1.60 m), before hemodialysis (BHD) and after hemodialysis (AHD).

Before HD session

<table>
<thead>
<tr>
<th>F(KHz)</th>
<th>R (Ω) Mean ± SD</th>
<th>-Xc (Ω) Mean ± SD</th>
<th>Z (Ω) Mean ± SD</th>
<th>-PA(°) Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>334.2 ± 63.7</td>
<td>292.5 ± 36.4</td>
<td>492.6 ± 86.6</td>
<td>90.3 ± 3.2</td>
</tr>
<tr>
<td>5</td>
<td>487.1 ± 83.4</td>
<td>37.8 ± 9.8</td>
<td>489.9 ± 84.4</td>
<td>4.4 ± 0.8</td>
</tr>
<tr>
<td>10</td>
<td>476.2 ± 96.5</td>
<td>9.9 ± 22.8</td>
<td>476.9 ± 96.7</td>
<td>1.6 ± 0.4</td>
</tr>
<tr>
<td>50</td>
<td>446.9 ± 66.5</td>
<td>57.2 ± 10.9</td>
<td>450.6 ± 94.3</td>
<td>7.6 ± 0.6</td>
</tr>
<tr>
<td>100</td>
<td>417.5 ± 87.3</td>
<td>100.6 ± 20.8</td>
<td>429.4 ± 89.6</td>
<td>14.1 ± 0.8</td>
</tr>
<tr>
<td>225</td>
<td>342.1 ± 73.5</td>
<td>178.9 ± 32.6</td>
<td>386.4 ± 79.7</td>
<td>28.3 ± 1.3</td>
</tr>
</tbody>
</table>
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Results

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

42 patients (26: M-16 F, 30-60 yr, 1.50-1.60 m), before hemodialysis (BHD) and after hemodialysis (AHD).

<table>
<thead>
<tr>
<th>F(KHz)</th>
<th>R (Ω) Mean ± SD</th>
<th>-Xc (Ω) Mean ± SD</th>
<th>Z (Ω) Mean ± SD</th>
<th>-PA(°) Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>449.8 ± 63.2</td>
<td>268.4 ± 35.9</td>
<td>542.6 ± 85.9</td>
<td>29.8 ± 3.2</td>
</tr>
<tr>
<td>5</td>
<td>530.1 ± 83.1</td>
<td>30.7 ± 9.6</td>
<td>530.5 ± 85.9</td>
<td>2.4 ± 0.5</td>
</tr>
<tr>
<td>10</td>
<td>512.7 ± 96.3</td>
<td>6.8 ± 22.4</td>
<td>512.7 ± 96.7</td>
<td>1.1 ± 0.5</td>
</tr>
<tr>
<td>50</td>
<td>485.8 ± 63.7</td>
<td>64.4 ± 11.5</td>
<td>489.6 ± 96.3</td>
<td>7.9 ± 0.7</td>
</tr>
<tr>
<td>100</td>
<td>457.2 ± 86.2</td>
<td>111.1 ± 21.4</td>
<td>464.6 ± 89.1</td>
<td>14.2 ± 0.8</td>
</tr>
<tr>
<td>225</td>
<td>372.9 ± 72.6</td>
<td>196.1 ± 33.2</td>
<td>420.8 ± 78.6</td>
<td>28.2 ± 1.3</td>
</tr>
</tbody>
</table>
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Results

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

Mean value of multi-frequency bioimpedance parameters (R and Xc, Z, PA) before BHD and after AHD session
II. Bioimpedance measurements in HD patients and relation with clinical state

☑ Results

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

Mean value of multi-frequency bioimpedance parameters (R and Xc, Z, PA) before BHD and after AHD session
II. Bioimpedance measurements in HD patients and relation with clinical state

✔ Results

BIVA. Monofrequency (50 kHz)

Mean impedance vectors with 95% confidence ellipse in pre-HD condition (Cuban patients) and pre-post condition (Italian patients)
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Results

BIVA. Monofrequency (50 kHz)

Mean RXc values for patients before HD and after HD compared with the tolerance ellipses (50%, 75%, and 95%) for the Cuban reference population.
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Results

BIVA. Monofrequency (50 kHz)

Confidence ellipses before HD
II. Bioimpedance measurements in HD patients and relation with clinical state

☑ Results

BIVA. Monofrequency (50 kHz)

Individual Z/H vector in tolerance ellipses
II. Bioimpedance measurements in HD patients and relation with clinical state

✅ Results

BIVA. Monofrequency (50 kHz)

### Statistical analysis BHD

<table>
<thead>
<tr>
<th>Gender</th>
<th>State</th>
<th>Size, N</th>
<th>R/H, Ω/m Mean SD</th>
<th>-Xc/H, Ω/m Mean SD</th>
<th>r(R/H, Xc/H) Mean SD</th>
<th>-PA, ° Mean SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Stable 19 ≤ BMI &lt; 30 age 18-70</td>
<td>28</td>
<td>289.1 40.7</td>
<td>26.6 6.5</td>
<td>0.9</td>
<td>5.2 0.8</td>
</tr>
<tr>
<td></td>
<td>Critical 20 ≤ BMI &lt; 22 age 18-70</td>
<td>16</td>
<td>244.8 45.5</td>
<td>17.7 4.8</td>
<td>0.8</td>
<td>4.1 0.8</td>
</tr>
<tr>
<td>Female</td>
<td>Stable 19 ≤ BMI &lt; 30 age 18-70</td>
<td>18</td>
<td>355.5 74.9</td>
<td>32.8 9.1</td>
<td>0.9</td>
<td>5.2 0.7</td>
</tr>
<tr>
<td></td>
<td>Critical 20 ≤ BMI &lt; 22 age 18-70</td>
<td>12</td>
<td>283.5 43.9</td>
<td>17.9 2.6</td>
<td>0.7</td>
<td>3.7 0.4</td>
</tr>
<tr>
<td></td>
<td>P (bilateral)</td>
<td></td>
<td>0.001</td>
<td>0.000</td>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

Student’s t test

Hotelling’s T2 test

<table>
<thead>
<tr>
<th>Gender</th>
<th>Women Z/H(R/H, Xc/H)</th>
<th>Men Z/H(R/H, Xc/H)</th>
<th>R/H SDx</th>
<th>-Xc/H SDy</th>
<th>r(YX)</th>
<th>R/H SDx</th>
<th>-Xc/H SDy</th>
<th>r(YX)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>42.5</td>
<td>5.9</td>
<td>0.8</td>
<td>64.5</td>
<td>7.3</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>P &lt; 0.05</strong></td>
<td></td>
<td></td>
<td><strong>P &lt; 0.05</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
II. Bioimpedance measurements in HD patients and relation with clinical state

☑ Discussion

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

Single vs. Multifrequency BIA in HD session (Piccoli et al. 2005)

...a Cole’s semicircle (mean of all patients) is shown for every time point of the dialysis sessions...(Table 2, Piccoli et al 2005)
II. Bioimpedance measurements in HD patients and relation with clinical state

✓ Discussion

Multifrequency (1, 5, 10, 50, 100, 225 kHz)

This error could be introduced due to **high electrode impedance**, the **anisotropy of muscle tissue** (Piccoli et al 2005), and **limitations on the bioimpedance analyzer** (at frequencies below 50 kHz the injected current is much lower due to safety reason).
1. The bioimpedance measurements considered as random vectors without prediction equations can provide useful information also in clinical conditions of abnormal body hydration as are observed in dialysis patients.

2. Our results demonstrate that there is a strong correlation between mortality and hyper-hydration (oedema) in patients undergoing HD, due to risk of cardiac failure present. Furthermore, the BIVA method could be used to detect hyper-hydration state before edema appears.
Sample size: 25 male patients
Classified taking into account the hydration state:
Normo-hydrated; (G0: 10 M, 55.6 ± 10.5 yr, BMI 24.0 ± 1.9 kg/m2)
Hyper-hydrated; (G1: 13 M, 56.6 ± 9.0 yr, BMI 29.5 ± 1.7 kg/m2).
Nephrology of the Fundaciò Puigvert (Barcelona, Spain)

To analyze the advantages of applying at the same time the BIVA method, (whole-body) and segmental, (longitudinal/transversal) bioimpedance measurements at 50 kHz in CAPD, and the relationship between bioimpedance parameters, hydration and nutritional state estimated by clinical assessment.
Two impedance based estimators were analyzed: Z, Z/H

AKERN-RJL System, USA-Italy
1) RS

2) THORAX

3) AB

Electrode position
4) TRABD

5) TRALEG

✓ Electrode position
To analyze the change in impedance (longitudinal and transversal) produced by a session of peritoneal dialysis (APD-BPD)

To analyze the separation between groups obtained by means of clinical diagnosis and those obtained by Z, Z/H.

To study the correlation between Z, Z/H vectors in each segment, with clinical assessment

Wilcoxon test

Mann-Whitney U test

The Spearman correlation
The Mahalanobis Distance

Was calculated for the mean blood pressure (BP_{mean}) and the impedance parameter R normalized by body height H for the right-side (R_{RS}/H) and the thorax segment (R_{TH}/H).

\[ dM^2 = (x - y)^T S^{-1} (x - y) \]

\[ dM^2 = (P_p - P_{ref})^T S^{-1} (P_p - P_{ref}) \]

Hotelling’s T2 test

To analyze the difference between groups (0 and 1) through (R_{TH}/H, BP_{mean}) and (R_{RS}/H, BP_{mean}) vectors.

Mann-Whitney U test

To compare the differences in clinical measurements, laboratory test, and bioimpedance measurements (R_{RS}/H and R_{TH}/H) between groups (0 and 1).
### Resultados

#### Tabla 1. Media ± SD de Z/H (R/H, Xc/H), y el test de Wilcoxon en una muestra de 10 pacientes (G0) en CAPD.

<table>
<thead>
<tr>
<th></th>
<th>R/H (Ω/cm) Media ± SD</th>
<th>P(R/H)</th>
<th>-Xc/H (Ω/cm) Media ± SD</th>
<th>P(Xc/H)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>APD</td>
<td>DPD</td>
<td>APD</td>
<td>DPD</td>
</tr>
<tr>
<td>RS</td>
<td>309.4 ± 29.9</td>
<td>323.5 ± 26.0</td>
<td>-</td>
<td>31.0 ± 6.2</td>
</tr>
<tr>
<td>TH</td>
<td>4.1 ± 1.1</td>
<td>4.3 ± 1.2</td>
<td>-</td>
<td>LS</td>
</tr>
<tr>
<td>AB</td>
<td>14.5 ± 2.3</td>
<td>17.7 ± 1.5</td>
<td>0.005**</td>
<td>LS</td>
</tr>
<tr>
<td>TRABD</td>
<td>19.4 ± 5.6</td>
<td>25.6 ± 4.3</td>
<td>0.009**</td>
<td>2.0 ± 0.6</td>
</tr>
<tr>
<td>RTRALEG</td>
<td>16.8 ± 3.5</td>
<td>17.7 ± 3.5</td>
<td>-</td>
<td>2.5 ± 1.0</td>
</tr>
</tbody>
</table>

#### Tabla 3. Resultado del test U de Mann-Whitney antes de la DP (Z/H).

<table>
<thead>
<tr>
<th></th>
<th>P(R/H)</th>
<th>P(Xc/H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>0.000**</td>
<td>0.010**</td>
</tr>
<tr>
<td>TH</td>
<td>0.000**</td>
<td>LS</td>
</tr>
<tr>
<td>AB</td>
<td>-</td>
<td>LS</td>
</tr>
<tr>
<td>TRABD</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RTRALEG</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### Tabla 2. Media ± SD de Z/H (R/H, Xc/H), y el test de Wilcoxon en una muestra de 15 pacientes (G1) en CAPD.

<table>
<thead>
<tr>
<th></th>
<th>R/H (Ω/cm) Media ± SD</th>
<th>P(R/H)</th>
<th>-Xc/H (Ω/cm) Media ± SD</th>
<th>P(Xc/H)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>APD</td>
<td>DPD</td>
<td>APD</td>
<td>DPD</td>
</tr>
<tr>
<td>RS</td>
<td>240.4 ± 31.4</td>
<td>255.2 ± 26.0</td>
<td>-</td>
<td>23.7 ± 6.6</td>
</tr>
<tr>
<td>TH</td>
<td>2.0 ± 1.3</td>
<td>2.2 ± 1.2</td>
<td>-</td>
<td>LS</td>
</tr>
<tr>
<td>AB</td>
<td>12.7 ± 2.5</td>
<td>14.4 ± 3.4</td>
<td>0.003**</td>
<td>LS</td>
</tr>
<tr>
<td>TRABD</td>
<td>19.8 ± 6.2</td>
<td>23.5 ± 7.2</td>
<td>0.006**</td>
<td>1.4 ± 0.6</td>
</tr>
<tr>
<td>RTRALEG</td>
<td>15.3 ± 5.4</td>
<td>15.5 ± 4.8</td>
<td>-</td>
<td>2.3 ± 1.1</td>
</tr>
</tbody>
</table>

#### Tabla 4. Correlación de Spearman entre Z/H segmental con la clínica

<table>
<thead>
<tr>
<th></th>
<th>Albumin (g/L)</th>
<th>CRP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rho P</td>
<td>Rho P</td>
</tr>
<tr>
<td>TH/H</td>
<td>0.564*</td>
<td>0.018</td>
</tr>
<tr>
<td>RLEGTOT</td>
<td>-</td>
<td>-0.520*</td>
</tr>
<tr>
<td>RTRALEG</td>
<td>0.633**</td>
<td>0.005</td>
</tr>
</tbody>
</table>

---

CRedB, UPC
BIVA in CAPD patients

Z-score of the standard, reference RXc-score graph (95% confidence interval)
1= Hyper-hydrated BPD, 2= Hyper-hydrated APD, 3= Normo-hydrated BPD,
4= Normo-hydrated APD
Hotelling’s T2 test in a sample of 25 male patients before CAPD

<table>
<thead>
<tr>
<th></th>
<th>G1 vs G0</th>
<th></th>
<th>G1 vs G0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(R_{RS}/H, \text{BP}_{\text{mean}})</td>
<td></td>
<td>(R_{TH}/H, \text{BP}_{\text{mean}})</td>
</tr>
<tr>
<td>R_{RS}/H</td>
<td>SDx</td>
<td>BP_{\text{mean}}</td>
<td>SDy</td>
</tr>
<tr>
<td>35.3</td>
<td>8.1</td>
<td>-0.5</td>
<td></td>
</tr>
</tbody>
</table>

Mahalanobis Distance

- \(R_{RS}, \text{BP}_{\text{mean}}\) G1
- \(R_{RS}, \text{BP}_{\text{mean}}\) G0
- \(R_{TH}, \text{BP}_{\text{mean}}\) G1
- \(R_{TH}, \text{BP}_{\text{mean}}\) G0
✓ Discussion (Second Study)
1. The real part of the impedance R has more sensibility for the detection of fluid changes produced by a dialysis session.

2. The segments with bigger changes after the dialysis session are the segmental measurements in the abdomen (longitudinal and transversal).

3. The best segments are the thorax and the right leg using longitudinal and transversal measurements.

4. To apply at the same time BIVA and segmental measures, could be an alternative method to know the hydric and nutritional state in CAPD patients.


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