

Continuous Monitoring of Body Fluids using Bioimpedance Measurements

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Continuous Monitoring of Body Fluids Using Bioimpedance Measurements

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Abstract

Bioimpedance Spectroscopy (BIS) allows to determine the human body composition (e.g. fat content, water content). From this data, conclusions can be drawn about the person's state of health. The technology can easily be implemented at a low cost, which could allow continuous monitoring at home (e.g. elderly people) or during clinical treatment (e.g. dialysis patients). The current BIS technology, however, requires laboratory conditions, which cannot be fulfilled in a continuous monitoring application. A concept of a system for the continuous monitoring of body fluids, which is based on BIS technology, is presented and evaluated in this thesis. The evaluation does not only include the construction of a BIS portable device, but also the performance of measurements using textile electrodes and the model-based correction of measurements. This specific correction is designed to eliminate external influences, normally compensated by laboratory conditions. Special focus has been given to the influence of changes in body posture and body temperature. In addition, the use of a segmental method of measurement (knee-to-knee) is proposed as an alternative to the whole body (wrist-ankle, or hand-to-foot) measurement. BIS has been measured on patients and healthy subjects in different situations at home and at the clinic. The results show that the model-based correction of measurements may be the key for continuous monitoring using BIS technology and that it could be combined with external sensors connected to the BIS device, in order to eliminate external influences, which all together will allow continuous monitoring with sufficient accuracy.

Zusammenfassung

Kontinuierliches Monitoring von Körperwassergehalt mit Hilfe von Bioimpedanz-Spektroskopie-Messungen. Die Bioimpedanz-Spektroskopie (BIS) ermöglicht die Bestimmung der Körperzusammensetzung (z.B. Fettgehalt und Gesamtkörperwasser). Diese Daten lassen auf den Gesundheitszustand einer Person schließen. Die BIS bringt niedrige Kosten und eine leichte Anwendbarkeit mit sich, wodurch sie als das kontinuierliche Monitoring zu Hause (z.B. bei älteren Menschen) oder in der Klinik (z.B. bei Dialysepatienten) einsetzbar ist. Allerdings kann die BIS-Technologie bisher nur unter Laborbedingungen durchgeführt werden, die im Rahmen eines kontinuierlichen Monitoring nicht erfüllbar sind. In dieser Arbeit wird das Konzept für ein BIS-basiertes System für die kontinuierliche Überwachung des Wassergehaltes vorgestellt und evaluiert. Hierbei wird nicht nur der Aufbau eines tragbaren BIS-Gerätes berücksichtigt, sondern auch die Möglichkeit einer Messung unter Anwendung von textilen Elektroden und die modellbasierte Korrektur der Messungen. Diese modellbasierte Korrektur wurde entwickelt, um externe Einflüsse, die normalerweise durch Laborbedingungen kompensiert werden, zu eliminieren. Der Schwerpunkt liegt auf den Einflüssen von Körperlage- und Körpertemperaturänderungen. Zusätzlich wird die Anwendung der segmentellen Messung (Knie-zu-Knie) als Alternative zur standardisierten Hand-zu-Fuß Methode vorgestellt. BIS-Messungen wurden an gesunden Probanden in verschiedenen Szenarien zu Hause und in der Klinik durchgeführt. Die Ergebnisse zeigen, dass die modellbasierte Korrektur der Messungen als neuartige Grundlage für das BIS basierte kontinuierliche Monitoring dienen könnte. Durch das Zusammenspiel von BIS-Technologie, modellbasierter Korrektur und externen Sensoren könnten die externen Einflüsse vermieden werden, was zu einem kontinuierlichen Monitoring mit der erforderlichen Messgenauigkeit führen würde.

List of Symbols and Abbreviations

Symbols

Symbol	Units	Meaning
A	cm^2	Cross-sectional area
c	-	Fractional volume of the nonconductive spheres embedded in a conductive medium
c_1, c_2	cm	Circumferences at both sides of a cylinder
C_m	nF	Membrane cell capacitance
C_{Pro}	mg/ml	Protein concentration
D_B	kg/m^3	Body density
d_{ECF}	kg/l	Extracellular fluid density
d_{ICF}	kg/l	Intracellular fluid density
g	m/s^2	Gravity acceleration
G	-	Gain
I_{Bias}	mA	Bias current
I_{Meas}	mA	Measurement current
K	ml/min/mmHg	Filtration coefficient
$K_{f,G}$	ml/min/mmHg	Glomerular filtration coefficient
K_B	-	Factor relating the height of a person with the proportions of the limbs
k_{ECF}	-	Constant factor for extracellular fluid in BCS technology
k_{ICF}	-	Constant factor for intracellular fluid in BCS technology
K_T	-	Constant factor relating interstitial and skin temperatures
K_ρ	-	Relationship between the resistivities of the intracellular and extracellular fluids
l	cm	Segmental length
$OSMP$	mOsm/l	Plasma osmolality
P_A	mmHg	Arterial pressure
P_{AS}	mmHg	Systemic arterial pressure
P_C	mmHg	Capillary pressure
$P_{C,G}$	mmHg	Glomerular capillary pressure
$P_{IntF,G}$	mmHg	Glomerular interstitial fluid (Bowman's capsule) pressure
P_{IntF}	mmHg	Interstitial pressure
P_V	mmHg	Venous pressure
Q	ml/min	Rate of filtration
Q_D	amount/(length ² · time)	Diffusion flux

Symbol	Units	Meaning
Q_E	Volts/bit	Quantization error
R	-	Correlation coefficient
R_A	(mmHg·min)/l	Resistance of arteriolar end of capillary
R_e	Ω	Extracellular resistance
R_i	Ω	Intracellular resistance
R_V	(mmHg· min)/l	Resistance of venular end of capillary
T_{IntF}	$^{\circ}\text{C}$	Interstitial temperature
T_{Skin}	$^{\circ}\text{C}$	Skin temperature
V	ml	Volume
V_B	ml	Body volume
V_{TC}	ml	Volume of a truncated cylinder
$Z_{Bipolar}$	Ω	Impedance measured using 2 electrodes
Z_{Body}	Ω	Body impedance
$Z_{Skin-Electrode}$	Ω	Skin-electrode Impedance
$Z_{Tetrapolar}$	Ω	Impedance measured using 4 electrodes
Π_C	mmHg	Capillary oncotic pressure
Π_{IntF}	mmHg	Interstitial oncotic pressure
$\Pi_{C,G}$	mmHg	Capillary oncotic pressure at the glomerulus
$\Pi_{IntF,G}$	mmHg	Interstitial oncotic pressure at the Bowman's capsule
ρ	$\Omega \cdot \text{cm}$	(Specific) electrical resistivity
ρ_B	kg/m^3	Blood density
ρ_a	$\Omega \cdot \text{cm}$	Effective electrical resistivity of a suspension
ρ_0	$\Omega \cdot \text{cm}$	Specific electrical resistivity of a suspension of conductive medium
ρ_{ECF}	$\Omega \cdot \text{cm}$	Electrical resistivity of the extracellular fluid
ρ_{ICF}	$\Omega \cdot \text{cm}$	Electrical resistivity of the intracellular fluid
ρ_{TBF}	$\Omega \cdot \text{cm}$	Electrical resistivity of the total body fluid
σ	$(\Omega \cdot \text{cm})^{-1}$	Specific electrical conductivity
Λ	$(\text{S} \cdot \text{cm}^2)/\text{mol}$	Molar conductivity
ω	rad/s	Electrical frequency

Abbreviations

Symbol	Units	Meaning
AC	-	Alternate current
<i>ADH</i>	pg/dl	Anti diuretic hormone (ratio to normal)
ADC	-	Analog to digital converter
ALD	ratio to normal	Aldosterone
AT	-	Adipose tissue
BIS	-	Bioimpedance spectroscopy
BCS	-	Bioimpedance composition spectroscopy
<i>BMI</i>	kg/m ²	Body mass index
<i>BV</i>	ml	Blood volume
CPE	-	Constant phase element
DC	-	Direct current
<i>ECF</i>	ml	Extracellular fluid
<i>ExF</i>	ml	Excess of fluid
<i>FFM</i>	kg	Fat free mass
<i>GFR</i>	l/min	Glomerular filtration rate
<i>H</i>	cm	Body height
<i>HDT</i>	°	Head down tilt
HF	-	Hand-to-foot
<i>HUT</i>	°	Head up tilt
<i>ICF</i>	ml	Intracellular fluid
<i>IntF</i>	ml	Interstitial fluid
Im	-	Imaginary part of a complex number
KK	-	Knee-to-knee
LT	-	Lean tissue
<i>M</i>	-	Magnitude
MSE	-	Mean square error
<i>OSMP</i>	mOsmol/l	Osmolality of plasma
<i>PV</i>	ml	Plasma volume
<i>QWU</i>	ml/min	Urine output
Re	-	Real part of a complex number
<i>RH</i>	%	Relative humidity
S	-	Segment
<i>TBF</i>	ml	Total body fluid
<i>UO</i>	l/min	Urine output
<i>W</i>	kg	Body mass or body weight

Contents

Acknowledgment	iii
Abstract	v
List of symbols and abbreviations	vii
1 Introduction	1
1.1 Aims of this Thesis	1
1.2 Organization of the Thesis	3
2 Fluid Physiology	5
2.1 Body Water Volume and Distribution in the Human Body	5
2.1.1 Influence of Age and Gender on Body Fluid Volumes	6
2.1.2 Extracellular Fluid (ECF)	8
2.1.3 Intracellular Fluid (ICF)	9
2.2 Body Fluid Regulation	10
2.2.1 Equilibrium in ECF between IntF and Plasma	11
2.2.2 Equilibrium between ECF and ICF	14
2.2.3 The Kidney	16
2.2.4 Thirst and Fluid Intake	18
2.2.5 Effects of Gravity	19
2.2.6 Effects of Temperature	23
2.3 Perturbations in the Body Fluid Regulation	25
2.3.1 Deficit of Body Water	25
2.3.2 Excess of Body Fluid	26
2.3.3 Renal Failure and Hemodialysis	27
2.3.4 Changes in Elderly People	28
2.4 Complexity and Meaning of the Body Fluid Measurements	29
2.4.1 Dilution Methods	30
2.4.2 BIA and BIS Methods	31
2.5 Summary	32
3 Bioimpedance Spectroscopy	33
3.1 Four-Point and Two-Point Measurement	33
3.2 The Skin-Electrode Interface	35
3.2.1 Representation using Ideal Elements	35
3.2.2 Representation using a Constant Phase Element	36
3.3 Calculation of Body Composition with BIS	39
3.3.1 Electrical Model: Cole Model	40
3.3.2 Physiological Modeling: Hanai Theory and Conductive Cylinder	41
3.3.3 Physiological Modeling for Segmental Measurements	43
3.3.4 Determination of Lean and Fat Tissue	44
3.3.5 Body Composition Determination using Hanai's Theory	44
3.3.6 Modified Hanai Theory and Tissue Hydration Model	45

3.4	Factors Influencing BIS Measurements	48
3.4.1	Body Position	48
3.4.2	Food and Drink Consumption	49
3.4.3	Body Temperature	49
3.4.4	Electrolytes	50
3.4.5	Analysis and Summary	51
3.5	Sensitivity, Precision and Accuracy of BIS Measurements under Laboratory Conditions	52
3.5.1	Precision and Accuracy Using Test-Dummies	52
3.5.2	Precision and Accuracy on Humans	53
3.6	Summary	54
4	Materials and Methods: Hardware Description and Measurements	55
4.1	Portability (Hypothesis 1)	55
4.1.1	General Construction of a BIS System	55
4.1.2	Hardware Design of a Portable BIS System (BISITO-I)	58
4.1.3	Safety Concept	60
4.2	Wearability: Alternatives to Standard BIS Electrodes (Hypothesis 2)	62
4.2.1	Textile Electrodes	62
4.2.2	Capacitive Electrodes	63
4.3	Wearability: Whole Body and Segmental Measurements (Hypothesis 3)	65
4.3.1	Comparison of Changes in KK and HF BIS Measurements	66
4.3.2	Influence of External Factors on KK and HF BIS Measurements and Their Relationship	68
4.4	Summary	71
5	Materials and Methods: Physiological Modeling	73
5.1	Model-Based Correction for Continuous BIS Measurements (Hypothesis 4)	73
5.2	Modeling of Continuous Segmental and HF Bioimpedance Measurements	74
5.2.1	11-Cylinder Model Combined with a Two-Pool Model	75
5.2.2	Influence of Changes in Body Posture	80
5.2.3	Influence of Changes in Environmental Temperature	80
5.2.4	Influence of Ultrafiltration during Hemodialysis	85
5.3	Influence of Body Position on the Kidney	86
5.3.1	Analysis of the Factors Influencing Kidney Function, depending on Body Position	86
5.3.2	Body Fluid Regulation Model	87
5.3.3	General Procedure of Modeling	87
5.4	Skin-Electrode Impedance	89
5.4.1	Equivalent Electrical Circuit Using Ideal Components	89
5.4.2	Equivalent Electrical Circuit Using the Constant Phase Element	90
5.5	Summary	90

6	Results	91
6.1	Portability: Hardware Development (Hypothesis 1)	91
6.1.1	Impedance Measurements, Cole Parameters and Body Fluids Calculation	92
6.1.2	Risk Analysis	93
6.2	Wearability: Alternatives for Standard BIS Electrodes (Hypothesis 2)	94
6.2.1	Textile electrodes	94
6.2.2	Capacitive Electrodes	96
6.3	Wearability: Whole Body and Segmental Measurements (Hypothesis 3)	97
6.3.1	Body Fluid Changes in HF and KK BIS Measurements	97
6.3.2	Influence of Body Posture	99
6.3.3	Food and Drink Consumption	101
6.3.4	Influence of Environmental Temperature	103
6.3.5	BIS Measurements for One Day and for One Week	107
6.3.6	Sensitivity, Precision and Accuracy of BIS During Continuous Measurements	109
6.4	Modeling and Model-Based-Correction (Hypothesis 4)	113
6.4.1	Correction of the Influence of Body Posture	113
6.4.2	Influence of Environmental Temperature	115
6.4.3	Simulation of Ultrafiltration during Hemodialysis	117
6.4.4	Influence of Body Posture on Kidney Function	119
6.4.5	Simulation of Skin-Electrode Interface	123
6.5	Summary	124
7	Discussion and Conclusions	126
7.1	Hypothesis 1	126
7.2	Hypothesis 2	126
7.3	Hypothesis 3	127
7.3.1	Required Precision to Detect Changes of Body Fluids Volumes	127
7.3.2	Hypothesis 3a	128
7.3.3	Hypothesis 3b	129
7.4	Hypothesis 4	133
7.5	Conclusions and Outlook	134
A	11-Cylinder Model Calculations	139
B	Physical Characteristics of the Subjects Participating in the Experiments	142
C	Testing the Validity of the Body Fluid Regulation Model	144
	References	149