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 Gesundheits-zustand einer Person schließen. Die BIS bringt niedrige Kosten und eine leichte Anwendbarkeit mit sich, wodurch sie als das kontinuierliches 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}	^{o}C	Interstitial temperature
T_{Skin}	^{o}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	Ω·cm	(Specific) electrical resistivity
ρ_B	kg/m^3	Blood density
ρ_a	$\Omega \cdot cm$	Effective electrical resistivity of a suspension
ρ_0	$\Omega \cdot cm$	Specific electrical resistivity of a suspension of conductive medium
ρ_{ECF}	$\Omega \cdot cm$	Electrical resistivity of the extracellular fluid
ρ_{ICF}	$\Omega \cdot cm$	Electrical resistivity of the intracellular fluid
ρ_{TBF}	$\Omega \cdot cm$	Electrical resistivity of the total body fluid
σ	(Ω· cm)$^{-1}$	Specific electrical conductivity
Λ	(S·cm^2)/mol	Molar conductivity
ω	rad/s	Electrical frequency

Abreviations

Symbol	Units	Meaning
AC	-	Alternate current
ADH	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
BMI	kg/m^2	Body mass index
BV	ml	Blood volume
CPE	-	Constant phase element
DC	-	Direct current
ECF	ml	Extracellular fluid
ExF	ml	Excess of fluid
FFM	kg	Fat free mass
GFR	l/min	Glomerular filtration rate
H	cm	Body height
HDT	^{o}	Head down tilt
HF	-	Hand-to-foot
HUT	^{o}	Head up tilt
ICF	ml	Intracellular fluid
$IntF$	ml	Interstitial fluid
Im	-	Imaginary part of a complex number
KK	-	Knee-to-knee
LT	-	Lean tissue
M	-	Magnitude
MSE	-	Mean square error
$OSMP$	mOsmol/l	Osmolality of plasma
PV	ml	Plasma volume
QWU	ml/min	Urine output
Re	-	Real part of a complex number
RH	%	Relative humidity
S	-	Segment
TBF	ml	Total body fluid
UO	l/min	Urine output
W	kg	Body mass or body weight

Contents