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The Combyn™ ECG: Adding haemodynamic and fluid leads for the ECG. Part II: Prediction of total body water (TBW), extracellular fluid (ECF), ECF overload, fat mass (FM) and "dry" appendicular muscle mass (AppMM)

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ABSTRACT

Simultaneous with a 12 channel ECG, body composition was analysed by segmental multi-frequency impedance analysis in 101 healthy subjects and in 118 patients with chronic heart failure (CHF, $n = 40$), chronic renal failure with haemodialysis (HD, $n = 20$), and miscellaneous internal diseases ($n = 58$). Whole body DXA and sodium bromide dilution were used as reference methods for total body water (TBW), extracellular fluid (ECF), appendicular muscle mass (AppMM) and fat mass (FM). Empirical prediction equations were developed in a randomized evaluation sample and then evaluated in unknowns. TBW, ECF, AppMM and FM could be predicted with regression coefficients of 0.96, 0.90, 0.95 and 0.93, respectively, all with $p < 0.001$. Only segmental impedances and height, but not age, sex, weight and BMI contributed to the prediction of water compartments. About half the patients with CHF and half of those on HD showed increased ECF/ICF ratio in relation to % FM at the legs but not at the thorax. The predicted AppMM was additionally corrected for increased ECF to determine "dry AppMM", which is markedly lower than the misleading reference DXA.

This methodology shows promise as a combination of routine ECG with measurement of body composition, assessment of sarcopenia and detection of overhydration.

1. Introduction

Even today, in the 21st century, traditional clinical signs such as pitting edema, skin fold and ocular bulbar tone, are still used to assess body composition, especially with regard to hydration. Here, the challenge would be to develop physical methods to provide objective, reliable data as a basis for optimal treatment [1,2]. Edema only becomes clinically apparent with an excess of at least 2.5 l of extracellular fluid (ECF) [1]. Optimal treatment of chronic heart failure (CHF) or chronic renal failure (CRF) with a haemodialysis [3,4] depends on assessment of dry weight. A means of assessing appendicular muscle mass (AppMM) would be desirable not only in the elderly [5], but in chronic heart and kidney failure as well [6]. When hydration varies, even a gold standard method like whole body DXA can produce misleading results, since it does not differentiate extracellular fluid accumulation from lean mass [7]. So far attempts to detect excess fluid by impedance have only been moderately successful [8,9,10]. In a previous paper [11] we showed that with suitable placement of ECG electrodes, segmental impedance spectroscopy can be used to detect not only overstretched heart muscle fibres and elevated BNP levels, but also segmental over-hydration in patients with chronic heart failure and effusion in body cavities. In this study, we aimed to predict total body water (TBW), appendicular muscle mass, fat mass (FM), ECF and ECF overload in a mixed sample of 101 healthy subjects and 118 patients with hydration derangement, e.g. in the context

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Abbreviations: ACE inhibitors, angiotensin-converting-enzyme inhibitor; AppMM, appendicular muscle mass; AT1 blocker, angiotensin-II-receptor-subtype-1 blocker; BMI, body mass index; BNP, brain natriuretic peptide; CHF, chronic heart failure; CRF, chronic renal failure; DXA, dual energy X-ray absorptiometry; ECF, extracellular fluid; ECG, electrocardiogram; FM, fat mass; HD, haemodialysis; ICF, intracellular fluid; LBM, lean body mass; NYHA, New York Heart Association classification; TBW, total body water.

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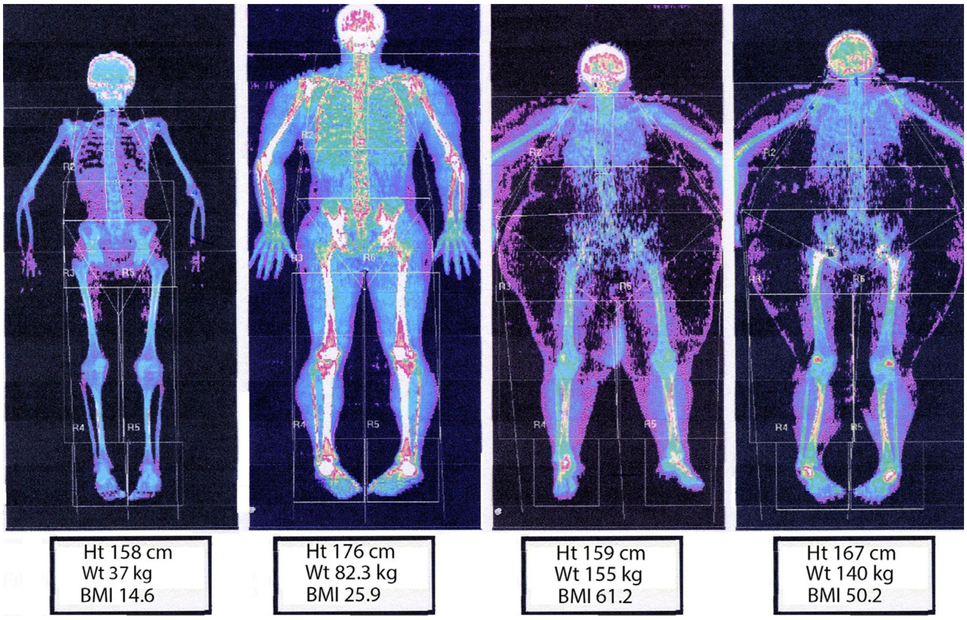

Fig. 1. Extreme examples of pathological body compositions analysed: a male patient with anorexia nervosa (BMI 14.6), an athletic male and two women with morbid obesity and BMIs of 50 and 61 are shown.

of chronic heart failure and long-term haemodialysis for chronic renal failure.

2. Material and methods

2.1. Subjects investigated

Two hundred and nineteen subjects were investigated: the 101 healthy controls were students at our institution or healthy members of a tennis or gymnastic club, or outpatients who were considered healthy after extensive work-up including abdominal and carotid ultrasound, echocardiography and biochemical screening. Consecutive patients referred to the Department of Internal Medicine and to the Institute of Cardiovascular and Metabolic Medicine were asked to volunteer for this study; 118 agreed and were included: 40 patients suffered from CHF due to coronary or hypertensive heart disease, NYHA class II, III, and IV (12, 15 and 13, respectively), and 20 patients from CRF before HD. The remaining patients had more than one diagnosis, so that the total number of diagnoses is greater than the number of patients. The other diagnoses were essential hypertension (13), coronary heart disease without clinical heart failure (12), atherosclerosis (11), chronic kidney disease stage II (24), stage III (22), stage IV (2), cancer (5), celiac disease (4), type II diabetes (3), morbid obesity (6), gastritis (1), chronic pancreatitis (1), type I and II osteoporosis (1), anorexia nervosa (2) and chronic polyarthritis (1). Patients already on treatment continued with their usual medications, including beta-blockers, ACE inhibitors, AT1 blockers, calcium channel blockers, hydrochlorothiazide, loop diuretics and spironolactone. Fig. 1 shows examples of the broad spectrum of subjects and patients included in the present study. The study complies with the Declaration of Helsinki; it was approved by the hospital's ethics committee and all patients gave written informed consent.

2.2. Methods

Patients were instructed to fast for 12 h before their appointments. A blood sample was taken from an antecubital vein to determine background sodium bromide concentrations. One hundred millilitres of tap water containing 676 mg sodium bromide were administered orally. To avoid additional sources of error, the doses were not normalized to body weight. After 4 h a second blood sample was taken. We measured height (Ht) to the nearest centimetre with a caliper while the subjects were standing and weight (Wt) with an electronic scale (Soehnle No. 7347) to the nearest 100 g.

2.3. Impedance measurements

The subjects rested supine with the upper body elevated at a 30° angle for at least 10 min. This position was chosen for the convenience of patients with dyspnea and/or heart failure. Electrodes were applied and the measurements performed as reported in part I of this publication [11] with some simplifications: the position of the electrodes is shown in Fig. 2. The leg and arm electrodes of the conventional ECG were replaced by double band clamp electrodes for the impedance measurements and the ECG. Leg electrodes were placed above the ankles, the arm electrodes above the wrist. The proximal leg electrodes, used in the first part of the paper, were omitted. Two spot adhesive ECG electrodes were applied on the right side of the neck. Current was passed between the outer neck and the outer left leg electrodes to measure the thoracic and abdominal segments, between the outer distal left and right leg electrodes to analyze the leg segments, and between the outer neck and outer arm electrodes for the arm measurements. The silver chloride double band electrodes and standard ECG spot electrodes were moistened with ECG electrode spray. The edge-to-edge distances between the current application and voltage pick-up electrodes were 3 cm.

Definition of the segments: The left thoracic segment was measured diagonally between the inner neck electrode and V4. The left abdominal segment was measured diagonally between V4 and the right leg electrode. The legs were measured alone between the inner neck and the inner leg electrodes using the contra-lateral leg as ionic current conductor. The arms were measured between the inner neck and the inner arm electrodes.

Segmental multi-frequency impedance measurements were performed at 5, 40 and 400 kHz, at the thorax, abdomen and both legs, respectively. These were chosen because evaluation of the data of our first paper [11] showed that these frequencies gave

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