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Preliminary Report

Near infra-red interactance for nutritional assessment of dialysis patients

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Abstract

Background. Malnutrition is a common problem in dialysis patients and may affect up to one-third of patients. Near-infrared interactance (NIR) is a novel approach to estimate body composition and per cent total body fat.

Methods. We used near-infrared interactance (Futrex 5000®) to estimate the body composition including body fat percentage, as well as subjective global assessment (SGA), anthropometric measurements including mid-arm circumference (MAC), triceps and biceps skinfold thickness, calculated mid-arm muscle circumference (MAMC), body mass index (BMI), and laboratory values. NIR score, SGA assessment and anthropometric parameters were measured shortly after the end of a dialysis session. NIR measurement was made by placing a Futrex® sensor on the non-access upper arm for several seconds. Serum albumin, transferrin (reflected by total iron binding capacity), and total cholesterol concentrations were performed as well.

Results. Thirty-four patients (20 men and 14 women) were selected from a pool of 120 haemodialysis patients. Their ages ranged from 26 to 86 years (58 ± 14 years). Time on dialysis ranged from 8 months to 19 years (4.5 ± 4.6 years). NIR scores were significantly different in three SGA groups: (A) well-nourished, $32.5 \pm 6.9\%$; (B) mildly to moderately malnourished, $29.2 \pm 5.3\%$; and (C) severely malnourished, $23.2 \pm 10.2\%$ ($P < 0.001$). Pearson correlation coefficients (r) between the NIR score and nutritionally relevant parameters were significant ($P < 0.001$) for body mass index ($r = +0.81$), mid-arm circumference ($r = +0.74$), triceps skin fold ($r = +0.54$), biceps skin fold ($r = +0.55$), and mid-arm muscle circumference ($r = +0.54$). An inverse correlation was also found between NIR and years dialysed ($r = -0.49$, $P = 0.004$), denoting a lesser body fat percentage according to NIR for patients dialysed longer. NIR was correlated with serum transferrin ($r = +0.41$, $P = 0.016$) and cholesterol ($r = +0.39$, $P = 0.022$) and marginally with serum albumin ($r = +0.29$, $P = 0.097$).

Conclusions. We conclude that NIR, which can be performed within seconds, may serve as an objective indicator of nutritional status in haemodialysis patients. More comparative and longitudinal studies are needed to confirm the validity of NIR measurements in nutritional evaluation of dialysis patients.

Key words: albumin; anthropometric measurements; dialysis; malnutrition; near-infrared (NIR); subjective global assessment (SGA); transferrin

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Introduction

Malnutrition in haemodialysis patients is common and may affect as many as one-third of patients [1,2]. Assessing nutritional status is important because protein–calorie malnutrition is a major risk factor for morbidity and mortality in dialysis patients [3,4]. There are several objective methods for assessing the nutritional status; however, all have shortcomings that hamper their systematic clinical application [1,5]. Anthropometric methods, which are unquestionably valuable, have inherent limitations and are impractical for many renal units. A number of recent reports have advocated the use of near-infrared interactance (NIR) for assessment of body compositions in different groups of patients [6–8]. NIR is a non-invasive, simple and rapid method for assessing the percentage of body fat; however, the method has not been rigorously tested in dialysis patients. To evaluate this method further, we compared the results of NIR to subjective global assessment (SGA), anthropometric measurements and accepted biochemical parameters in a randomly selected group of dialysis patients.

Subjects and methods

The patients

Our university-hospital-affiliated dialysis programme in Staten Island, New York, currently serves over 120 patients. We selected those patients who had never changed their modality of treatment (changed to peritoneal dialysis or transplantation), who had required no hospitalizations in the month prior to the study, who had no signs of infections or disease activity (collagen vascular disease), and who agreed to participate. Thirty-four haemodialysis patients (20 male and 14 female) agreed to enroll into the study and their data were obtained and analysed. Our institutional review committee approved the protocol and written, informed consent was obtained from all participants.

Patients age ranged from 26 to 86 years (58 ± 14 years). They had undergone dialysis from 8 months to 19 years (4.5 ± 4.6 years). All received erythropoietin, 500–15 000 units (4706 ± 3633 units) thrice weekly, as well as oral or intravenous iron supplementation for at least 2 months prior to the study. The 'dry' body weight was the average oedema-free weight immediately at the end of the haemodialysis sessions.

Nutritional assessment

NIR is a non-invasive, simple, and rapid method of assessing the percentage of body fat and is based on light absorption and reflection using near-infrared light emission [7]. We used a commercially available NIR measuring device, Futrex 5000A/ZL® (Futrex Inc., Galthersburg, Maryland), which is a portable, 900 g, $12 \times 24 \times 5.5$ cm mini-computer and is based on technology from the United States Department of Agriculture, with an NIR measurement estimating range between 2.5 and 50.0% [9]. The main body is connected *via* a light cable to a microphone-size light-emitting sensor. The NIR sensor window is to be equipped with a light shield prior to placing it on the mid upper arm to ensure that no external light interferes with the estimation of percentage body fat. Only a few seconds are required to enter patient's data into the mini-computer and to obtain the NIR measurement while the sensor remains on the arm. In our study, NIR measurement was made by placing the Futrex 5000® sensor on the non-access upper arm of each dialysis patient for several seconds. All measurements were performed between 10 and 20 min after the termination of the dialysis session. Each patient underwent only one measurement, since a pilot study on 10 normal and 10 dialysis subjects showed that the NIR scores were extremely reproducible (less than 5% variability) as long as the same arm is used.

Body dry weight and skin fold measurements were performed between 10 and 20 min immediately after termination of the dialysis session. Biceps skin fold (BSF) and triceps skinfold (TSF) were measured with a conventional skinfold caliper. Mid-arm circumference (MAC) was measured with a metal tape measure. All above measurements were performed three times on the non-access arm of each dialysis patient prior to NIR measurements and the average number of the three measurements was registered as the final result. Mid-arm muscle circumference (MAMC) was derived according to the following formula: $\text{MAMC} = \text{MAC} - (3.1415 \times \text{TSF})$. Body mass index (BMI) was calculated as the ratio between end dialysis body weight and the square of height.

The Subjective Global Assessment (SGA) was used to assess overall nutritional status of all patients. The SGA, which was originally developed to assess nutritional status in hospitalized patients post-operatively [10], has also been applied to nutritionally deprived patients in other clinical settings, including haemodialysis [2,11]. The assessment is based on the history and physical examination as described by Detsky *et al.* [10]. The history consists of five criteria and focuses on weight loss in preceding 6 months, gastrointestinal symptoms (anorexia, nausea, vomiting, diarrhoea), dietary food intake, functional capacity, and co-morbidities. Each of these features are scored separately in terms of A (normal or well nourished), B (partially abnormal or moderately malnourished), or C (extremely abnormal or severely malnourished). The physical examination includes three items that focus on loss of subcutaneous fat over the triceps and mid-axillary line of the lateral chest wall, muscle wasting in the deltoids and quadriceps, and the presence of ankle oedema and/or ascites. These features are classified as: 0 = normal, 1 = mild, 2 = moderate, and 3 = severe. The data are weighted and the patients are then classified in terms of three major SGA scores: A = well nourished, B = moderate malnutrition, or C = severe malnutrition. Details on the SGA for use in dialysis patients are available in Internet as the appendix of our recently published manuscript [2]. We performed the SGA at two different sessions; a physician and a renal nutritionist (dietitian) performed the test independently. Differences in SGA assessment results were noticed on four patients or less than 15% of our study population (inter-rater reliability of 0.85) and were resolved by a combined assessment consensus of the two observers.

Laboratory evaluation

The following laboratory parameters were measured on all patients immediately prior to the dialysis session: serum albumin, total protein, total cholesterol, serum total iron binding capacity (TIBC) to estimate transferrin, serum iron, transferrin saturation ratio (iron saturation ratio), serum ferritin, haemoglobin, serum creatinine, and blood urea nitrogen. Post-dialysis blood urea nitrogen of the same dialysis session and pre-dialysis blood urea nitrogen of the following dialysis session were measured as well in order to calculate the urea reduction ratio (URR) and protein catabolic rate (PCR). Red blood cell indices and haemoglobin, as well as albumin, cholesterol and TIBC values (colorimetric method) were obtained by automated methods. The haematocrit was measured by centrifugation. The serum ferritin value was measured by an immunoradiometric assay with polyclonal reagents. Serum TIBC concentrations were used to calculate transferrin values [12]. The urea reduction ratio (URR) was obtained by calculating the percentage of intradialytic reduction of blood urea nitrogen [2,12]. URR correlates closely with Kt/V in haemodialysis patients [4]. Thus, URR was used as the indicator of the haemodialysis efficacy in our study. The protein catabolic rate (PCR) was calculated by equation of Gotch and Sargent based on the interdialytic urea appearance rate [13].

Statistics

We used Pearson's correlation r, and Spearman rank correlation coefficient (non-parametric testing with Spearman rho) for selected analysis. Two-sample student t test was used for group mean comparisons between men and women. Analysis of variance (F test) was used for group mean comparison within SGA categories. Simple and multiple regression analyses were carried out to obtain the regression equations. Box and whisker plot was used to depict NIR score distribution within SGA categories. Descriptive statistics and regression analyses were carried out with a statistical software (Statistica for Windows, Release 5.1, Statsoft, Inc., Tulsa, Oklahoma). Fiducial limits are given as mean ± standard deviation (SD). A P value of <0.05 was accepted as statistically significant.

Results

Table 1 shows summary of data for all patients as well as for each gender-specific group. Women were on average 3 years older than men. NIR scores were significantly different between men and women. NIR-measured body fat percentage in women (33.2 ± 8.4%) was about 6% higher than that in men (27.1 ± 6.7%). Similar differences between two groups were noticed in biceps and triceps skinfolds, both slightly higher in women than men. Men were significantly taller, but their body mass index (BMI) was only slightly greater than the average BMI in women. There were no gender-specific, differences in mid-arm circumference (MAC), calculated mid-arm muscle circumference (MAMC), urea reduction ratio (URR) or protein catabolic rate (PCR). Similarly the serum chemistries did not show significant differences except for serum albumin which was 0.3 g/dl lower in women, compared to men.

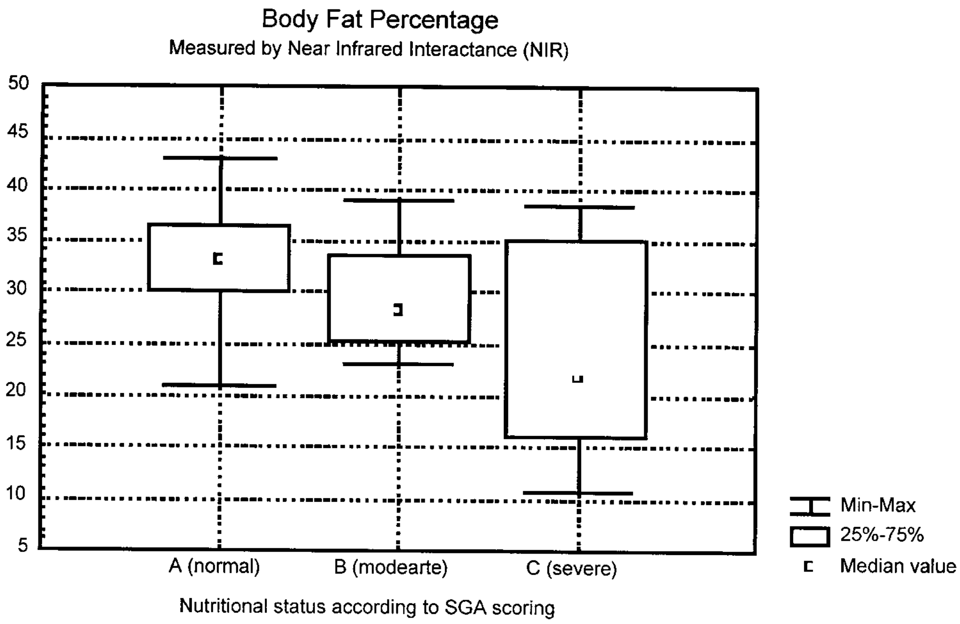

Fig. 1. Near infrared (NIR) scores within three SGA groups (box and whisker plot).

Table 1. Data of all patients and their gender specific sub-groups (mean ± standard deviation)

Parameter	All patients ($n=34$)	Men ($n=20$ (59%))	Women ($n=14$ (41%))	P-value
Age (years)	57.8 ± 13.8	56.7 ± 14.2	59.4 ± 13.6	0.573
Weight (kg)	78.7 ± 22.7	84.9 ± 22.9	69.9 ± 19.9	0.056
Height (m)	1.69 ± 0.11	1.74 ± 0.10	1.62 ± 0.08	0.001
BMI (kg/m^2)	27.5 ± 7.3	27.9 ± 6.8	27.0 ± 8.3	0.725
Years dialysed	4.53 ± 4.55	4.49 ± 5.27	4.58 ± 3.46	0.959
URR (%)	63 ± 11	64 ± 9	62 ± 14	0.625
PCR	0.986 ± 0.655	1.093 ± 0.760	0.833 ± 0.451	0.261
NIR (%)	29.6 ± 7.9	27.1 ± 6.7	33.2 ± 8.4	0.026
Biceps SF (mm)	7.4 ± 4.7	6.2 ± 3.0	9.1 ± 6.1	0.080
Triceps SF (mm)	11.4 ± 10.6	8.1 ± 4.4	16.1 ± 14.7	0.030
MAC (cm)	28.1 ± 5.4	27.9 ± 4.3	28.6 ± 6.9	0.710
MAMC (cm)	24.6 ± 4.1	25.3 ± 3.5	23.5 ± 4.8	0.224
Albumin (g/dl)	3.9 ± 0.3	4.0 ± 0.3	3.7 ± 0.3	0.025
Transferrin (mg/dl)	214 ± 40	213 ± 36	215 ± 46	0.884
Cholesterol (mg/dl)	169 ± 41	167 ± 38	173 ± 47	0.678
Creatinine (mg/dl)	10.4 ± 3.3	11.3 ± 3.5	9.2 ± 2.5	0.057

P-values <0.05 are significant for gender differences. BMI, body mass index; URR, urea reduction ratio; PCR, protein catabolic rate; NIR, near infrared; SF, skin fold; MAC, mid-arm circumference; MAMC, mid-arm muscle circumference.

Table 2 shows the clinical and laboratory data in three different SGA sub-groups. Seventeen patients (50%) were well-nourished (group A), 10 patients (29%) were mildly to moderately malnourished (group B), and seven patients (21%) were poorly nourished (group C). Figure 1 shows NIR scores according to SGA semi-quantitative levels (box and whisker plot). The NIR scores were significantly different in the three SGA groups: group A had 32.5±6.9%, group B had 29.2±5.3%, while group C had 23.2±10.2% ($P=0.027$). Similar significant differences among three different SGA categories were observed in mid-arm muscle circumference, biceps and triceps skinfolds, serum transferrin, and number of years on dialysis.

Table 3 shows Pearson correlation coefficients (r) among relevant parameters. Correlation coefficients (r) between NIR and other parameters were statistically significant ($P<0.001$) for body mass index ($r=+0.81$), mid-arm circumference ($r=+0.74$), triceps skinfold ($r=+0.54$), biceps skinfold ($r=+0.55$) and calculated mid-arm muscle circumference ($r=+0.54$). A significant, inverse correlation was also found between NIR and years dialysed ($r=-0.49$, $P=0.004$), denoting that patient who has been on haemodialysis longer had a lower body fat percentage. Older dialysis patients appeared to have lower NIR measured fat percentage depicted by a near significant inverse correlation between NIR and age ($r=-0.32$, $P=0.067$). Among the laboratory parameters, NIR showed a statistically significant correlation coefficient with serum transferrin ($r=+0.41$, $P=0.016$) and serum cholesterol ($r=+0.39$, $P=0.022$). The relationship between NIR and serum albumin ($r=+0.29$; $P=0.097$) approached signficance. NIR did not show a significant correlation with protein catabolic rate (PCR); however, there was a significant inverse correlation between NIR and URR ($r=-0.41$; $P=0.017$). Further correlation analyses within gender-specific subgroups revealed similar significant correlation coefficients ($P<0.05$) between NIR and MAC (male $r=+0.59$, female $r=+0.92$) and MAMC (male $r=+0.61$, female $r=+0.75$). Figures 2 and 3 depict the relationship between NIR (y axis) and biceps skinfold and mid-arm circumference (x axis) respectively, along with their simple regression equations.

The multiple regression equations for NIR on the basis of biceps skinfold and mid-arm muscle circumference (MAC) with over 95% confidence was as following: $\text{NIR}=3.8+0.4435\times\text{BICEPS}+0.4292\times\text{MAMC}$. There were significant regression beta values for both biceps skinfold ($\beta=0.4435\pm0.1342$, $P=0.002$) and MAMC ($\beta=0.4292\pm0.1342$, $P=0.003$). The F test calculated multiple regression analysis revealed a highly significant correlation between NIR and the other two independent variables ($r=0.6907$, $F(2,31)=14.141$, $P<0.00004$, standard error of estimate $=5.913$).

Discussion

We showed that NIR correlated well with the SGA and all anthropometric measurements as well as most nutritionally relevant laboratory parameters in haemodialysis patients. The three SGA nutritional subgroups showed significantly different NIR measured body fat percentage values having the highest NIR scores in well-nourished patients (SGA class A) and lowest in severely malnourished patients (SGA class C). The correlation was especially robust for body mass index ($r=0.81$) and mid-arm circumference ($r=0.74$). NIR also showed significant correlations with other anthropometric parameters including triceps and biceps skin-

Table 2. Patients' age, years haemodialysed, and other nutritional and laboratory data (mean±SD) in terms of SGA categories

	Subjective global assessment (SGA)			*P* value
	Score A (normal or well-nourished)	Score B (mildly to moderately malnourished	Score C (severely malnourished)	
Number of patients	$n=17$ (50%)	$n=10$ (29%)	$n=7$ (21%)	
NIR (%)	32.5±6.9	29.2±5.3	23.2±10.2	0.027
MAMC (cm)	25.2±3.5	25.0±2.8	22.3±6.4	0.272
MAC (cm)	30.5±4.7	26.9±2.9	24.1±7.4	0.017
Biceps SF (mm)	9.5±5.6	6.0±2.1	4.5±2.4	0.028
Triceps SF (mm)	16.8±12.7	6.1±1.3	5.8±4.0	0.007
Transferrin (mg/dl)	226±40	214±35	182±33	0.039
Albumin (g/dl)	3.8±0.3	4.0±0.2	3.7±0.4	0.098
Cholesterol (mg/dl)	165±47	174±28	173±47	0.853
Creatinine (mg/dl)	11.8±3.2	10.7±3.0	9.5±3.3	0.057
Age (years)	58.8±12.7	53.7±18.7	61.3±7.2	0.510
Years dialysed	3.22±2.64	3.76±2.25	8.80±7.79	0.015
BMI (kg/m^2)	29.5±7.3	26.7±6.2	23.8±8.2	0.205
URR (%)	61.3±14.6	64.2±5.9	66.4±8.1	0.588
PCR	0.825±0.208	1.208±1.153	1.061±0.295	0.331

ANOVA (analysis of variance) *P* values <0.05 are significant for group differences. NIR, near infrared; MAMC, mid-arm muscle circumference; MAC, mid-arm circumference; SF, skinfold; BMI, body mass index; URR, urea reduction ratio; PCR, protein catabolic rate.

Table 3. Pearson rank correlation coefficients

Parameter	NIR	SGA	BMI	MAMC	MAC	Biceps SF	Triceps SF
SGA	+0.45 (0.008)						
BMI	+0.81 (0.001)	+0.31 (0.073)					
MAMC	+0.54 (0.001)	+0.25 (0.153)	+0.64 (0.001)				
MAC	+0.74 (0.001)	+0.48 (0.004)	+0.73 (0.001)	+0.79 (0.001)			
Biceps SF	+0.55 (0.001)	+0.44 (0.008)	+0.37 (0.030)	+0.25 (0.150)	+0.67 (0.001)		
Triceps SF	+0.54 (0.001)	+0.47 (0.005)	+0.41 (0.017)	+0.05 (0.764)	+0.65 (0.001)	+0.79 (0.001)	
Transferrin	+0.41 (0.016)	+0.42 (0.013)	+0.38 (0.027)	+0.25 (0.153)	+0.28 (0.106)	+0.19 (0.282)	+0.15 (0.396)
Albumin	+0.29 (0.097)	+0.16 (0.377)	+0.30 (0.089)	+0.49 (0.003)	+0.32 (0.065)	−0.08 (0.656)	−0.09 (0.615)
Cholesterol	+0.39 (0.022)	−0.09 (0.633)	+0.43 (0.011)	+0.30 (0.082)	+0.29 (0.094)	+0.14 (0.442)	+0.10 (0.569)
Creatinine	−0.16 (0.356)	−0.20 (0.261)	+0.32 (0.065)	+0.12 (0.484)	+0.07 (0.712)	−0.17 (0.330)	−0.05 (0.793)
Age	−0.32 (0.067)	−0.02 (0.903)	−0.37 (0.033)	+0.05 (0.761)	−0.07 (0.691)	+0.09 (0.628)	−0.18 (0.301)
Years dialysed	−0.49 (0.004)	−0.43 (0.010)	−0.41 (0.016)	−0.47 (0.005)	−0.44 (0.009)	−0.30 (0.083)	−0.15 (0.409)
PCR	+0.02 (0.932)	−0.19 (0.284)	+0.06 (0.716)	+0.11 (0.519)	−0.01 (0.966)	−0.08 (0.636)	−0.15 (0.383)
URR	−0.41 (0.017)	−0.18 (0.300)	−0.42 (0.014)	−0.25 (0.148)	−0.36 (0.035)	−0.32 (0.065)	−0.28 (0.109)

P values are in parentheses. Significant *P* values are <0.05. SGA, subjective global assessment; BMI, body mass index; MAMC, mid-arm muscle circumference; MAC, mid-arm circumference; SF, skinfold; PCR, protein catabolic rate; URR, urea reduction ratio.

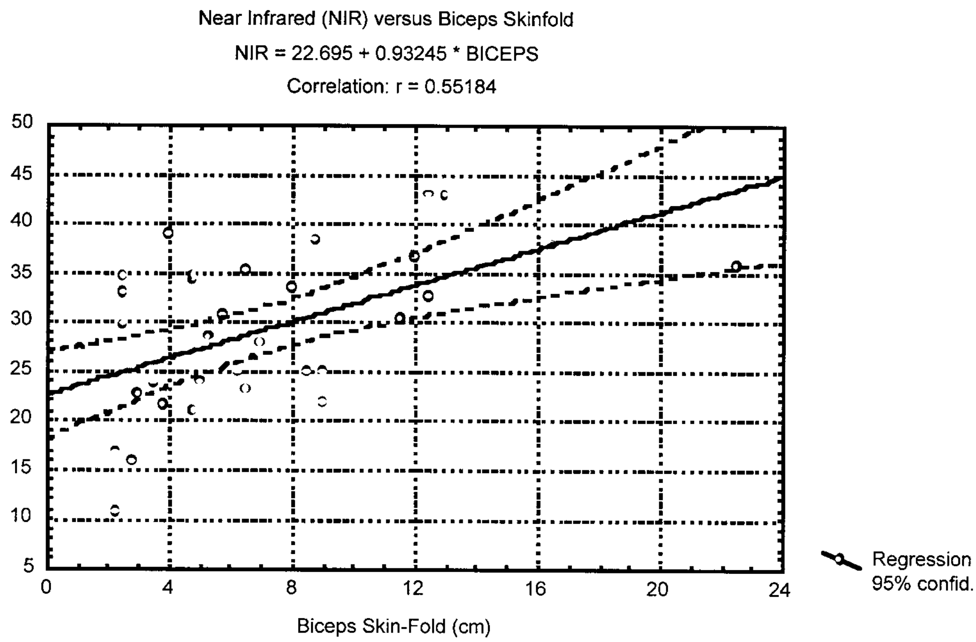

Fig. 2. Correlation between near infrared (NIR) and mid-arm muscle circumference (MAMC).

folds and mid-arm muscle circumference. There was a significant, inverse correlation between NIR and the years dialysed. This result corresponds to our earlier study based on subjective global assessment (SGA), in which we showed that the poorly nourished dialysis patients had the longer dialysis times [2]. We also found significant correlations between NIR and serum transferrin and cholersterol concentrations as well as a near-significant correlation between NIR and serum albumin. These relationships would likely have been even stronger had we examined more subjects. Although our findings are preliminary, we believe that NIR might be a promising method for quickly assessing nutritional status in dialysis patients.

NIR is based upon the principles of light absorption and reflection using near-infrared spectroscopy [7]. When electromagnetic radiation strikes a material, the energy is reflected, adsorbed or transmitted depending on the scattering and absorption properties of the sample. Energy scattered and reflected back out of the sample contains information about the chemical composition of the sample [7]. The use of near-infrared light interactance to determine body composition was first investigated by Conway *et al.* [14], who showed that near-infrared spectral data from the biceps of the dominant arm alone resulted in correlation coefficients equal to hydrostatic densitometry (underwater weighing) values. Infrared measures from the biceps have been the primary site shown to correlate best with the standard methods [6,14]. The biceps site appears to be the most representative of total body fat, since the combination of skin and subcutaneous fat thickness at the biceps allows optimal penetration and interactance of the low level of infrared radiation [14]. In this study, we used a commercially available version for NIR measurement (Futrex 5000®) which is easily available in the US and most European countries at a reasonable price (currently even slightly lower than the price of the commercial versions of bioelectrical impedance analysis) and is specifically designed to estimate body fat percentage on the basis of NIR measurements of the upper arm [9].

The reliability of NIR in determining body composition is supported by earlier studies [6,8,15]. Yasukawa *et al.* examined 94 healthy subjects and found a correlation $r > 0.8$ between NIR score and body composition estimated by anthropometric measurements [16]. Elia *et al.* [6] found a highly significant correlation between NIR and body composition as measured by whole-body densitometry although they concluded that NIR might underestimate body fat in very obese subjects. Recently Young *et al.* [17] compared several body composition assessment methods to evaluate their accuracy for patients with cardiac disease for the purpose of outcome measurement and reported that NIR presented the best standard error of estimates (3.5%) and the best correlation ($r = 0.84$) with hydrostatic weighing. They elaborated that, in the future, NIR measurements may be a viable technique for body composition assessment in patients with cardiac disease although NIR consistently underestimated percent body fat when compared to hydrostatic weighing in this population [17].

NIR has been applied in patients with chronic renal failure in earlier studies. Soreide *et al.* [18] used NIR to show an increase total body fat during peritoneal dialysis. Svarstad *et al.* [19] used NIR scores to measure total body fat and total body water in 24 male haemodialysis and 17 male peritoneal dialysis patients. They observed significantly different NIR scores in these two group of patients and concluded that NIR could serve to detect time-dependent differential changes in body composition. Kaufmann *et al.* [20] used NIR, along with anthropometric and biochemical parameters, to investigate the impact of long-term haemodialysis on nutritional status. Lo *et al.* [21] and Keshaviah *et al.* [22] compared different measurements of lean body mass and included NIR in their studies as well. However, none of these investigators studied the accuracy of NIR as an independent parameter for assessing nutritional status in dialysis patients.

Our study did not show a correlation between NIR and protein catabolic rate (PCR). PCR is a parameter of momentary protein intake and may not reflect the overall nutritional state. The inverse correlation between NIR and URR was another unexpected result. However, we did not use the average URR or average PCR of the last several months, but only the last calculated value at the time of NIR. It is possible that this result indicates that larger, well nourished dialysis patients receive an inadequate dialysis prescription [23]. Conceivably estimation of nutrition with NIR could draw attention to that fact.

Our study is limited by small numbers and lack of longitudinal follow-up. More elaborate methods such as dual-energy X-ray absorptiometry (DEXA) and bioelectrical impedance (BIA) are required to further evaluate the validity of NIR in dialysis patients. Nevertheless, we are encouraged by these preliminary findings. NIR is extremely user-friendly and requires only seconds to perform. NIR-estimated body fat percentage may replace the more cumbersome anthropometric measurements in dialysis units, especially if its validity is corroborated by longitudinal studies

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