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Short title: Doubling diet fat on sugar ratio in mitochondriopathies

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Abbreviations:
ANOVA : Analysis Of Variance.
BD : Basal Diet
CD : Challenging Diet
CONSORT : Consolidated Standards of Reporting Trials
DIT : Diet Induced Thermogenesis
MOD : Mitochondrial OXPHOS Disorder
OXPHOS : Oxidative Phosphorylation
REE : Resting Energy Expenditure

SUMMARY

Background and aims: Mitochondrial OXPHOS disorders (MODs) affect one or several complexes of respiratory chain oxidative phosphorylation. An increased fat/low-carbohydrate ratio of the diet was recommended for treating MODs without, however, evaluating its potential benefits through changes in the respective contributions of cell pathways (glycolysis, fatty acid oxidation) initiating energy production. Therefore, the objective of the present work was to compare Resting Energy Expenditure (REE) under basal diet (BD) and challenging diet (CD) in which fat on sugar content ratio was doubled. Diet-induced thermogenesis (DIT) and body compositions were also compared. Energetic *vs* regulatory aspects of increasing fat contribution to total nutritional energy input were essentially addressed through measures primarily aiming at modifying total fat amounts and not the types of fats in designed diets.

Methods: In this randomized cross-over study, BD contained 10% proteins/30% lipids/60% carbohydrates (fat on sugar ratio = 0.5) and was the imposed diet at baseline. CD contained 10% proteins/45% lipids/45% carbohydrates (fat on sugar ratio = 1). Main and second evaluation criteria measured by indirect calorimetry (QUARK RMR®, Cosmed, Pavona; Italy) were REE and DIT, respectively. Thirty four MOD patients were included; 22 (mean age 13.2±4.7 years, 50% female; BMI 16.9±4.2 kg/m^2) were evaluated for REE, and 12 (mean age 13.8±4.8 years, 60% female; BMI 17.4±4.6 kg/m^2) also for DIT. OXPHOS complex deficiency repartition in 22 analysed patients was 55% for complex I, 9% for complex III, 27% for complex IV and 9% for other proteins.

Results: Neither carry-over nor period effects were detected (p=0.878; ANOVA for repeated measures). REE was similar between BD *vs* CD (1148.8±301.7 *vs* 1156.1±278.8 *kcal/day ;* p=0.942) as well as DIT (peak DIT 260 *vs* 265 *kcal/day ;* p=0.842) and body composition (21.9±13.0 *vs* 21.6±13.3 % of fat mass *;* p=0.810).

Conclusion: Doubling diet fat on sugar ratio does not appear to improve, per se, energetic status and body composition of patients with MODs.

Keywords: Mitochondrial disorders or diseases, Energy expenditure, Diet induced thermogenesis, Body composition.

1. Introduction

Mitochondrial OXPHOS disorders (MODs) encompass a group of rare genetic disorders affecting respiratory chain oxidative phosphorylation (OXPHOS) and resulting from mitochondrial or nuclear DNA defects [1,2]. The OXPHOS system plays a key role in transferring energy from macronutriments to ATP through a sequence of coordinated reactions by which macronutriments are oxidized. OXPHOS comprises five major protein-lipid enzyme complexes which are located in mitochondrial inner membrane and work locally in synergy with the labile electron acceptors ubiquinone (an amphiphilic isoprenoid compound) and cytochrome *c* (a 12 kDa peptide). Electrons generated during glucose, fatty acids and amino acid oxidations are channeled across complexes I and II to be transferred sequentially to coenzyme Q10, complex III, and complex IV. Complexes I, III, and IV use part of the energy produced by the electron transfer flux to extrude protons across the mitochondrial inner membrane, from mitochondrial matrix to mitochondrial intermembrane space. The resulting proton gradient is consumed with energy utilization and production by complex V which condenses adenosine diphosphate and inorganic phosphate into adenosine trisphosphate (ATP) [3,4]. These overall mechanisms and players for ATP production are impaired in disorders affecting OXPHOS, jeopardizing various cell functions notably those which require a high energy supply. [5]. Currently, no satisfactory curative treatment for MODs exists. Only symptomatic treatments of MODs are available [2,7,8]. Interestingly, dietary modulations have been considered as regards to the key-role of mitochondria in energy production from macronutrients [9,10].

Increasing fat *vs* carbohydrate content in the diet has been recommended for the treatment of MOD. Several reasons justify this recommendation. (*i*) Mitochondrial oxidation of NADH is thought to be diminished in MOD [5,11] patients especially those affected with respiratory chain Complex I (CI) deficiencies, it might be by-passed by $FADH_2$, an alternative carrier of reducing equivalents, the electrons of which can enter the respiratory chain distal to complex I. (*ii*) Supply in $FADH_2$ to the mitochondria can be increased (relative to NADH) by increasing the amount of triacylglycerols and fatty acids in the diet. On the basis of stoichiometry of mitochondrial oxidations, fatty acids yield a ratio of FADH to NADH of 0.5, whereas glucose yields a much lower ratio of 0.2. In addition, fatty acids in contrast to glucose are endowed with uncoupling properties towards OXPHOS [12]. Though uncoupling OXPHOS lowers net ATP production by mitochondria, it virtually accelerates mitochondrial respiration through increased

electron transfer rates, a feature which improves mitochondrial oxidations regulated by the NADH/NAD+ and FADH2/FAD ratios.

In the wake of this rationale, we hypothesized that increasing fat to glucose ratio within an isoenergetic and isonitrogenous diet should improve energy substrate oxidation in MOD patients. As a corollary, this dietary measure should actually increase resting energy expenditure (REE), an assumption also based on *in vitro* data on human cell [13,14] and animal studies [15], and *in vivo* data obtained in complex I deficiency mitochondrial myopathy patients [16–19]. The aim of the present study was, therefore, to study REE under basal diet (referred throughout the manuscript to as the basal diet (BD)) challenged by a diet in which fat on carbohydrate content ratio was doubled (referred to as the challenging diet (CD)) as a potential treatment in children with a MOD. In these children, diet induced thermogenesis (DIT) and body composition were also measured to get a better account for whole body energetic balances under the two diets.

2. Materials and methods

2.1. Trial design and participants

This 3-year prospective study (2008-2011) included MOD patients from the reference centers for Inherited Metabolic Diseases of Lille and Paris (Jeanne de Flandre Lille University Hospital ; Robert Debré Paris University Hospital). Inclusion criteria were : (*i*) Child or adult between 5 to 21 years with MOD [20], (*ii*) MOD subjects given a stable balanced diet having the characteristics of basal diet (BD : 60 % carbohydrates, 30 % lipids, 10 % proteins) for at least one month. Subjects were excluded from the study when they required hospitalization or presented with any acute condition (such as infection) known to interfere with energy metabolism assessment.

As shown in flow CONSORT diagram [21] on (Figure 1), from 36 MOD subjects included over a period of four years, 22 accepted compliance to the diets and examinations, and were analysed for principal evaluation criterion (*ie* REE in Group 2), and from these 22, only 12 accepted to undergo the secondary evaluation criterion (*ie* DIT in Group 3).

This study was a randomized cross-over study (Figure 2). Method used to generate sequence was a simple randomisation by one-to-one allocation ratio. Subject randomisation was performed using sealed envelopes. REE were measured at four time points (*ie* Visit 1: baseline, Visit 2: after one month of basal or challenging diet ; Visit 3: after wash-out period consisted of one month of BD ; and Visit: 4 after one month of basal or challenging diet; see Figure 2). Neither

carry-over effect, nor period effect was detected (p = 0.878 ; ANOVA for repeated measures). All assessments were performed in two Clinical Investigation Centers (CIC-1403-Inserm-CH&U of Lille; CIC-9202-Inserm-AP-HP of Paris). Before each assessment visit, all subjects arrived by car to the Clinical Investigation Center at 8:00 h, being fasted from 20:00 h on the previous day. Weight and height were first measured, and then compliance with the imposed diet was evaluated.

2.2. Nutrition protocol management

Intervention of the trial consisted of a CD diet period of one month (*ie* 10 % proteins, 45 % lipids, 45 % carbohydrates). CD and BD diets were isoenergetic and isonitrogenous diets.

Each patient was randomly assigned to the basal diet (BD) for the control period *vs* the challenging diet (CD) for the intervention period. Each one-month period was thereafter inversed according to a cross-over trial. BD consisted of 10 % proteins, 30 % lipids, 60 % carbohydrates. To reach this BD, research dieticians used a specific booklet communicated to subjects and/or their parents to lower fat intake. CD consisted of 45 % lipids, 45 % carbohydrates ; 10 % proteins.

DIT was performed after a calibrated breakfast corresponding to 20% of recommended daily energy intake according to Martin *et al*'s formula [22]. According to the cross-over design, breakfast had a BD in control period and a CD in intervention period. Basal content breakfast consisted of bread, skimmed milk and jam. Challenging breakfast consisted of bread, full-cream milk and chocolate paste. After breakfast, meals were re-weighted and diet energy supplies were analysed by the difference between served and returned meals [23].

The assessment of energy intake and diet composition was performed using dietary record technique previously reported [24]. The technique used a specific chart report form including how to record the foods consumed, using size instruments such as pictures of graduated bowls, cups, dishes, number of spoons. Each file corresponding to one day was separated in four parts: breakfast, lunch, dinner and snack. Lunch and dinner were detailed as starter, main course, and desert [25]. Both oral and written instructions were given to each patient and/or parents on how to keep accurate records using the size instruments, and the parents assisted the children in recording, identifying and quantifying the foods consumed. Subjects detailed daily food intakes on the specific chart report form during 7 d [26]. The same project related dietician reviewed each specific chart report. Quantification of meals and drinks were checked by the same trained dietician, the parents and the child together. The dietician was well trained to identify both miss and over-reporting and coherency of food records. The portion sizes were estimated using a three dimensional portion size instrument with French current meal food photographs corresponding to

171 an exact BILNUT software (version 6 : Paris, France). This method has been shown to give unbiased
172 records of energy intake in lean subjects up to 9 y old and showed that children aged 8-15 y were
173 able to estimate food quantity to within = 10 % of the amount really eaten, suggesting that
174 children could quantify their food intake with reasonable accuracy [27].
175
176 *2.3. Indirect calorimetry assessment of energy expenditure*
177 The subject rested recumbent on a hospital bed watching a videotape for 15 min. Same
178 quiet cartoons or videos (depending on age range of the subject) were used for all the subjects
179 [28]**.** Oxygen consumption (Vo_2 in mL/min) and carbon dioxide production (Vco_2 in mL/min) were
180 determined by using the open-circuit indirect calorimeter validated QUARK® RMR (Cosmed,
181 Pavona di Albano, Italy). The validity and accuracy measurements were guaranteed by yearly
182 calibration of the flow settings by the manufacturer of the calorimeter and guaranty a high
183 accuracy of QUARK® RMR between study centres [29]. Calibration of zero, span and delay
184 alignment of the O_2 and CO_2 gas analyzers was performed daily before each test using a certified
185 calibration gas.
186 The QUARK® RMR was equipped with a canopy hood for spontaneously breathing subjects.
187 With this device, flow rate was directly measured with a digital turbine flowmeter. Accuracy of the
188 flowmeter was 2%. Ventilatory rate was regulated directly by the QUARK® RMR. During each test,
189 the readings were controlled and eventually compensated by means of periodic automatic room
190 air calibrations. Response times of O_2 and CO_2 sensors were less than 120 *ms*. The O_2 analyzer was
191 a paramagnetic sensor, which had a measuring range from 0 to 30% in the canopy mode. Accuracy
192 of the O_2 sensor was 0.02 %. The CO_2 analyzer was an infrared digital sensor with a measuring
193 range standing from 0 to 10%. Accuracy of the CO_2 sensor was 0.02%. The flow meter which
194 detects the ventilation rate of the canopy was a bidirectional turbine with an 18 *mm* diameter.
195 The ventilation range was from 0 to 80 L/min. Accuracy of the flowmeter was 2%. QUARK® RMR
196 software utilized the Weir equation to assess Resting Energy Expenditure (REE) [30].
197 DIT was measured at two occasions (Visit 2 and Visit 4) after REE measurement. DIT was
198 derived from postprandial energy expenditure (PEE) as described by Dabbech M *et al* [31]. PEE
199 assessment started immediately after a calibrated breakfast (see above for energetic ratio). DIT
200 was computed by subtracting REE from PEE (*ie* DIT = PEE – REE) according to Dabbech M *et al* [31].
201
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203

204 *2.4. Assessment of body composition by Dual X-ray Absorptiometry*

205 The DXA (Dual X-Ray Absorptiometry) instrument was a Lunar DPX-IQ ‘‘pencilbeam’’ (Lunar
206 Radiation Corporation, Madison, WI, USA). Whole-body scan time was 560–590 s, and the
207 radiation dose was less than 0.03 *mrem* (¼ 0.3 *mSv*). Total body image acquisition and analysis
208 were obtained by following strictly manufacturer’s specified instructions. The use of two photon
209 energies reduced errors due to irregular soft-body-mass and body contours. Two photon energies
210 discriminated two substances in a given system to a high accuracy. When more than two
211 substances, the discrimination depended on the number of additional substances, their
212 attenuation characteristics, and their relative contents [32]. FFM (fat-free mass), FM (fat mass) and
213 weight were calculated using the software provided by the manufacturer, and was adapted for the
214 subject age.

215

216 *2.5. Regulatory requirement*

217 The protocol was approved by French appropriates regulatory authorities (Direction
218 Générale de la Santé; DGS 2007-A0018-50) and ethical review committee (Comité de Protection
219 des Personnes Nord-Ouest IV ; CPP 07/32). Study protocol was also declared to clinical trial.gov
220 register (NCT02385565). Participation in the study was voluntary and written informed consent
221 was obtained from both parents and children. Written informed consent was obtained by the
222 subject when patient was aged over 18 years.

223

224 *2.6. Statistical analysis*

225 Required sample size was computed using previously published data from complex I
226 deficiency (CID) mitochondrial myopathy patients [16,17] with REE = 1120 ± 93 Kcal/min in basal
227 condition (Glucose infusion). REE obtained in hyperlipid MOD condition (Triacylglycerol infusion)
228 were 5 % higher at 1175 ± 93 Kcal/min. We hypothesised a 10% difference of REE between basal
229 and challenging diets. According to the cross-over study design of the study and 80% statistical
230 power, the sample size was defined at 20 patients to detect a significant difference between diets.

231 Statistical analyses were performed using SAS V.9 (Cary, USA). According to a Shapiro-
232 Wilk test, all variables had a normal distribution. In this context, parametric test $\chi 2$ for ratio, and
233 to a cross-over trial design**:** period effect was tested by ANOVA analysis for repeated measures,
234 carry over effect was tested by Student *t* test. Difference between two diets was tested by Student
235 *t* test when number of subjects was above 15 [33,34]. When number of subjects was under 15, we

used non-parametric tests: *ie* Wilcoxon for paired analyses and Mann-Whitney for non-paired analyses.

3. Results

3.1. Anthropometric, biochemical defects and main clinics of enrolled patients

Anthropometric characteristics of patients from each of the 3 groups defined in the flow CONSORT diagram illustrated at Figure 1 are presented on Table 1. No statistical differences were observed between included and analysed subjects for REE, and DIT measurements. Table 2 further summarizes main clinical and biochemical results of respiratory chain activities in skeletal muscle and/or cultured skin fibroblasts. The most frequent defect was complex I deficiency at 55% (n=12). Table 3 presents a minimum set for anthropometric data description of patients with complex I deficiency and those with other defects. There was no difference between groups excepted for Z-score BMI which was significantly lower in the group of patients with defects other than complex I deficiency.

3.2. Study of patients undergoing REE measurements

3.2.1. Food intakes

Food intakes in fat, carbohydrates and proteins were determined during the cross-over periods in the 22 patients undergoing REE measurements (Table 4).

3.2.2. Metabolic REE measurements and anthropometrics

As mentioned in the experimental section, REE were measured at four time points (see Figure 2). No carry-over effect and no period effect was detected for the present study ($p = 0.878$; ANOVA for repeated measures).

Table 5 presents full metabolic data at baseline and after basal *vs* challenging diet conditions. Measured REE were close to the predictive REE. No significant differences were observed between the basal and challenging periods for any parameters (*ie* Vo_2, Vco_2, REE, RQ) even when these parameters were adjusted by body composition parameters (*ie* weight, fat mass, fat free mass, muscle weight). Patient body composition parameters did not also differ between basal and challenging diet periods for whole analyzed population (table 6). There were no differences between basal and challenging diet periods for measured REE and anthropometrics in patients with complex I deficiency nor in the group of patients affected by others defects. (Tables 7 and 8)

3.3. Study of patients undergoing DIT measurements

3.3.1. Food intakes

In a subset of 12 subjects, it was possible to measure DIT. Table 9 presents respective carbohydrate, lipid and protein contents of basal and challenging breakfasts. According to these data, designed diet conditions (*ie* basal *vs* challenging) were in practice respected

3.3.2. DIT measurements

Figure 3 gives time-courses of DIT over a postprandial period of 250 *min*. Maximum DIT was obtained at 100 ± 27 *min* after basal breakfast and 122 ± 29 *min* after challenging breakfast ($p = 0.861$). No significant differences in DIT optima, areas under the curve, time durations of postprandial periods were observed between basal *vs* challenging diet conditions. Similarly, RQ during DIT measurements were not significantly different between basal and challenging diet conditions (Figure 4).

4. Discussion

Because of the well-established ability of fats to induce mitochondrial biogenesis, we aimed to test efficacy of an increased fat on carbohydrate ratio of the diet to manage nutrition in MODs in order to improve energy expenditure metabolism [15–18]. Our study was designed to determine to what extent and how REE, and secondarily DIT and body composition, may be impacted by doubling fat *vs* carbohydrate contribution to nutritional energy intake. The collected data do not confirm our primary hypothesis of a higher REE in challenging diet conditions. Therefore, they do not *a priori* corroborate previous benefits suggested for high-fat diet in MODs in a specific subset of patients using a specific type of fat enrichment. Our study present several strengths (*i*) the cross-over design that is perfectly adapted to the aims of our study and the rarity and heterogeneity of MODs, without period and carry-over effect, (*ii*) an adequate sample size, (*iii*) a very well controlled diet, (*iv*) a well characterized population and (*v*) the use of gold standard methodology based on previously validated tools (*ie* indirect calorimetry, body composition

analysis). Duration of the cross-over periods of one month was considered to be sufficient for a high stability of energy metabolism and changes in REE and DIT. The absence of differences of REE between basal and challenging diets observed in our study might be explained either by the wide genetic heterogeneity usually observed in subjects with a mitochondrial disease [35], and masking the power/homogeneity effect or by no impact of the challenging diet on REE, DIT and body composition. In this respect, majority of previous trials have been performed on complex I MOD [15,16,36,37] and, until now, trials mixing patients with distinct complex deficiencies were lacking. The present study overcomes this gap and allows comparison with previous studies, some extra statistical analyses were performed on REE and body composition in the subset of complex I MOD patients included in our study. These extra analyses did not detect any difference in REE and body composition in this subset of patients (Tables 7 and 8). This result does not reject the heterogeneity of our population as a cause mentioned above for a lack of benefit of challenging diet in MODs as even in Complex I defect, there is a huge genetic variability [38]. Concerning durations of the cross-over period, one month was an adapted period to observe any changes in REE and DIT in view of one week as a known successful period to normalize complex I activity in malnourished patients [37]. We did not observe any difference in DIT (*ie* energy expenditure and RQ) as Flatt observed in healthy subject [39,40]. The last hypothesis of the lack of impact of CD on energy metabolism despite a higher amount of energy intake at breakfast (+ 37 % see Table 9) might result from the fact that the CD tested was at a 45% instead of a 50% dietary fat content, though no effect of CD was also observed by De Meer K et al [41]. An important feature also is that our CD was primarily aimed at doubling fat *vs* carbohydrate contribution to nutritional energy intake and not to enrich fat qualitatively with a specific type of fats. Using a specific type of fat Roef *et al* [16] found that triacylglycerol infusion improved some metabolic parameters (*ie* VCo_2, respiratory quotient) during physical exercise in a sample of patients with deficient complex I. The significant effect observed in their study may be accounted for by several factors :

(i) a specific effect of triacylglycerol intravenous infusion which is more energetic efficient than oral intake because of a high rate of systemic delivery and contents in medium-chain triglycerides (MCT). MCT are more energetic efficient that long-chain triglycerides because of their faster handling by metabolic pathways. This advantage is used in ketogenic diets where high fat ratios force the body to use fats instead of carbohydrates [42]. The underlying energetic change in oxidative

phosphorylation (OXPHOS) lies in fatty acids yielding a ratio of FADH to NADH of 0.5, whereas glucose yields a much lower ratio of 0.2

(ii) measurements performed during a physical exercise occur during sustained substrate oxidation, allowing a better detection of differences in energetic metabolism,

(iii) a specific population response (only 4 subjects in this study). The absence of response in our population even if we analyzed a subgroup of complex I-deficient patients might be attributed to the lack of mechanisms covered by parenteral route, MCT and physical exercise which are all conditions absent from our experimental protocols. This does not preclude that the ketogenic diet does not improve mitochondrial oxidations as a source of metabolic energy, but this feature unfortunately failed to be detected by our study. In this respect, the lower fat enrichment of our CD vs classic ketogenic diet (43.6 % of fat in our CD *vs* 90% in ketogenic diet) is another aspect to take into account.

As MODs may exhibit a wide range of symptoms including developmental delay, seizures, vision and hearing impairments, autonomous nervous dysfunction, gastrointestinal signs, endocrine disturbances and failure to thrive, a special interest of these symptoms were checked during the study period. No adverse reactions, adverse events of special interest, or serious adverse events were observed excepted some fatigue in 6 patients from 24 randomized patients only during basal diet period (not significant). As a whole, doubling fat *vs* carbohydrate contribution to nutritional energy intake does not improve, *per se*, energetic status and body composition of patients with MODs but does not also impact negatively patients. However, undernutrition observed in defects other than complex I could suppose a higher defect in weight energy balance in these patients *vs* complex I-deficient patients.

5. Conclusion

As a whole, this study does not provide evidence that doubling fat *vs* carbohydrate ratio of the diet increases whole-body energy expenditure in patients with MOD. We were not able to

demonstrate a lowering of the metabolic challenge induced by substrate oxidation as a suggested potential benefit in CD for mitochondrial diseases [5]. Our study suggests that underlying mechanisms for a potential beneficial effect for CD does not a priori involve modulations of REE, nor DIT. The wide heterogeneity of the studied population and/or the amount/quality of lipids in the diet might play a role as well in the generated data and subsequent conclusions

Conflict of Interest Statement & Statement of Authorship.

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Table 1
Anthropometric characteristics of total included subjects and those undergoing REE and DIT measurements. Results are expressed as mean values ± SD.

	Group 1 *Total included subjects*	**Group 2** *Analysed subjects for REE*	**Group 3** *Analysed subjects for DIT*	**p-value** *(group 1 vs 2)*	**p-value** *(group 1 vs 3)*
n	**36**	**22**	**12**	NA	NA
Female (%)	48	50	60	0.837[#]	0.916[∅]
Age : *Year*	13.2 ± 4.7	13.2 ± 4.6	13.8 ± 4.8	1.000[§]	0.823[§]
Weight: *kg*	36.3 ± 15.8	36.8 ± 15.9	40.2 ± 18.4	0.928[§]	0.765[§]
Height: *cm*	143.8 ±22.1	143.4 ± 20.2	148 ± 21.3	0.918[§]	0.811[§]
BMI: *Kg/m²*	17.0 ± 4.1	16.9 ± 4.2	17.4 ± 4.6	0.924[§]	0.875[§]
Z-score BMI	-0.96 ± 1.6	-0.94 ± 1.68	-0.75 ± 1.59	0.878[§]	0.749[§]
Fat mass: *%*	23.1 ± 12.9	22.22 ± 12.3	22.3 ± 11.5	0.888[§]	0.902[§]
[Σ] **FFM**: *Kg*	28.6 ± 11.7	23.3 ± 11.5	32.9 ± 12.2	0.817[§]	0.396[§]
[Σ] **Muscle:** *Kg*	26.9 ± 10.3	22.1 ± 12.4	30.8 ± 9.4	0.902[§]	0.753[§]

BMI = Body Mass Index
NA = Not Applicable
NS = Not Significant
FFM = Fat Free Mass measured by [Σ]DEXA

= χ^2 test : ∅ = χ^2 test with Yates correction

§ = Student *t* test

Table 2
Repartition of respiratory chain complex deficiencies in the group of REE analysed subjects along with their main clinical signs (n=22; group 2). Mitochondrial respiratory chain enzyme activities were assessed by biochemical measurements on skeletal muscle biopsy or on cultured skin fibroblasts; diagnoses of MELAS and MNGIE were made on the basis of molecular studies.

Complex deficiency	n	Neurological signs	Muscular signs	Neuro-sensitive signs
I	12*	7	1	0
III	2**	2	2	1
IV	6	6	0	0
MELAS [1]	1	1	0	0
MNGIE [2]	1	1	0	0
TOTAL	**22**	**16**	**3**	**1**

[1] MELAS = Myoclonic Epilepsy Lactate Acidosis and Stroke like episodes with mutation 3243A>G (mitochondrial DNA).
[2] MNGIE = MyoNeuroGastro Intestinal Encephalopathy with mutation C130T-G128A.
* 3 of 12 patients are simultaneously deficient for complexes I, II and III.
** 2 patients are simultaneously deficient for complexes III and IV.

Table 3
Comparison between anthropometric characteristics of respiratory chain-deficient subjects with and without complex I deficiencies in the group analysed for REE and body composition. Results are expressed as mean values ± SD.

	Patients with complex I deficiency	Patients with other defects	p-value
n	**12**	**10**	NA
Female (%)	61	56	0.395∅
Age : *Year*	12.5 ± 4.5	14.3 ± 4.9	0.693§
Weight : *kg*	39.9 ± 15.9	33.5 ± 15.4	0.376§
Height : *cm*	142.6 ± 18.3	144.4 ± 23.1	0.927§
Z-score BMI	-0.06 ± 1.6	-2.0 ± 1.11	**0.010**§

BMI = Body Mass Index
NA = Not Applicable
FFM = Fat Free Mass measured by $^{\Sigma}$DEXA

∅ = χ^2 test with Yates correction

§ = *U-Mann Whitney test*

Table 4.
Food parameters during cross over periods for REE analysed subjects (n=22 group 2). Results are expressed as mean values ± SD.

	Cross-over periods			
	Baseline[a]	**BD**	**CD**	**p-value** (BD *vs* CD)
Energy Intake: *Kcal/d*	1722.2 ± 366.1	1729.6 ± 401.6	1950.0 ± 593.5	0.089 §
Carbohydrates: %	55.0 ± 4.0	53.8 ± 4.9	43.1 ± 3.1	**<0.001** §
Lipids: %	29.3 ± 3.6	31.1 ± 2.9	43.6 ± 2.5	**<0.001** §
Proteins: %	15.1 ± 3.4	15.1 ± 3.3	13.3 ± 2.3	0.24 §

[a] Baseline is during a basal diet period
[b] significant
BD = Basal diet : CD = Challenging diet
§ = Paired student *t* test

Table 5.
Metabolic parameters at rest of analysed subjects (n= 22 group 2) at baseline, after basal diet or after challenging diet. Results are expressed as mean values ± SD.

	Cross-over periods			
	Baseline	**BD**	**CD**	**p-value** (BD *vs* CD)
Vo_2				
Vo_2 *ml/min*	210.5 ± 42.5	205.6 ± 54.2	204.7 ± 43.8	0.904§
Vo_2 *ml/min/kg* of body weight	4.5 ± 2.1	4.8 ± 2.0	4.8 ± 2.1	0.899 §
Vo_2 *ml/min/kg* of FFM	5.4 ± 2.3	6.1 ± 2.3	6.9 ± 4.2	0.775 §
Vo_2 *ml/min/kg* of muscle	5.8 ± 2.2	6.5 ± 2.3	6.5 ± 2.3	0.939 §
VCo_2				
VCo_2 *ml/min*	243.2 ± 55.5	235 ± 60.1	240.7 ± 51.9	0.842 §
VCo_2 *ml/min/kg* of body weight	5.3 ± 2.3	4.5 ± 1.9	4.4 ± 2.2	0.810 §
VCo_2 *ml/min/kg* of FFM	6.4 ± 2.4	5.6 ± 2.0	6.2 ± 3.8	0.436 §
VCo_2 *ml/min/kg* of muscle	6.9 ± 2.3	6.0 ± 2.1	5.9 ± 2.4	0.332§
REE				
REE *Kcal/d*	1229.6 ± 303.8	1148.8 ± 301.7	1156.1 ± 278.8	0.942 §
$^{\Sigma}$pREE *Kcal/d*	1192.4 ± 232.4	1191.0 ± 246.7	1200 ± 245.2	0.934 §
REE *Kcal/d/kg* of body weight	38.1 ± 13.7	34.7 ± 11.8	35.7 ± 15.1	0.720 §
REE *Kcal/d/kg* of FFM	46.4 ± 13.7	43.3 ± 12.3	50.2 ± 28.9	0.624§
REE *Kcal/d/kg* of muscle	49.1 ± 13.0	49.9 ± 12.4	48.1 ± 16.2	0.834 §
RQ				
mRQ	0.86 ± 0.10	0.87 ± 0.08	0.85 ± 0.10	0.834 §
pRQ	0.87 ± 0.11	0.88 ± 0.10	0.84 ± 0.10	0.729 §

[a] Baseline is during a basal diet period
[b] significant
BD = Basal diet: CD = Challenging diet
REE = Resting Energy Expenditure
pREE = Predictive Resting Energy Expenditure
FFM = Fat Free Mass
mRQ = Measured Respiratory Quotient (measured VO_2/measured VCO_2)
pRQ = Predictive Respiratory Quotient (theoretically calculated from the nutritional contents of diets in each class of energetic substrates [carbohydrates, lipids and proteins])
§ = Paired student *t* test
§ = Paired student *t* test
$^{\Sigma}$Predictice REE calculated by Harris and Benedict equation

Table 6.
Body composition parameters of subjects (n= 22) undergoing REE evaluations at baseline, after one month of basal diet and after one month of challenging diet. Results are expressed as mean values ± SD.

	Cross-over periods			
	Baseline	**BD**	**CD**	**p-value** (BD *vs* CD)
Weight : Kg	38.8 **±** 15.9	36.6 **±** 13.7	38.5 ± 18.0	0.698 §
Fat mass : %	22.1 **±** 12.3	21.9 ± 13.0	21.6 ± 13.3	0.810 §
FFM : *Kg*	29.3 **±** 11.5	29.1 ± 12.2	26.8 ± 11.0	0.716 §
Muscle : *Kg*	26.9 **±** 10.3	26.6 ± 11.1	26.5 ± 11.0	0.810 §

FFM = Fat Free Mass
§ = Paired student *t* test
[a] Baseline is during a basal diet period
[b] significant
BD = Basal diet : CD = Challenging diet

Table 7.
Minimum set of metabolic and anthropometrics data in complex I deficient subjects (n= 12) undergoing REE evaluations at baseline, after one month of basal diet and after one month of challenging diet. Results are expressed as mean values ± SD.

	Cross-over periods			
	Baseline	**BD**	**CD**	**p-value** (BD *vs* CD)
REE *Kcal/d*	1229.6 ± 258.2	1139.5 ± 250.3	1158.2 **±** 255.5	0.695 §
RQ	0.75 ± 0.12	0.88 **±** 0.14	0.82 **±** 0.08	0.366 §
Weight: *Kg*	39.9 ± 15.9	40.2 ± 16.2	40.6 ± 16.1	0.948 §
Fat mass: *%*	27.9 **±** 14.5	25.1 ± 15.9	26.1 ± 16.5	0.790 §
FFM: *Kg*	29.8 **±** 8.9	28.9 ± 9.8	28.3 ± 9.8	0.657 §
Muscle: *Kg*	26.9 **±** 8.2	26.5 ± 9.3	25.8 ± 9.1	0.929 §

FFM = Fat Free Mass
§ = Wilcoxon test
[a] Baseline is during a basal diet period
[b] significant
BD = Basal diet; CD = Challenging diet

Table 8.
Minimum set of metabolic and anthropometrics data of subjects with a respiratory chain defect other than complex I (n= 10) and undergoing REE evaluations at baseline, after one month of basal diet and after one month of challenging diet. Results are expressed as mean values ± SD.

	Cross-over periods			
	Baseline	**BD**	**CD**	**p-value** (BD *vs* CD)
REE *Kcal/d*	1195.1 **±** 361.2	1166.5 ± 378.5	1157.0 ± 316.3	0.875 §
RQ	0.80 **±** 0.15	0.81 **±** 0.16	0.89 ± 0.12	0.555 §
Weight: *Kg*	33.5 **±** 15.4	34.5 **±** 15.5	34.5 **±** 15.4	0.948 §
Fat mass: *%*	15.8 **±** 4.6	17.5 ± 6.4	16.6 ± 6.1	0.109 §
FFM: *Kg*	28.7 **±** 14.3	29.2 ± 15.5	25.2 ± 12.6	0.248 §
Muscle: *Kg*	26.7 **±** 12.7	26.8 ± 13.7	27.3 ± 13.2	0.185 §

FFM = Fat Free Mass
§ = Wilcoxon test
[a] Baseline is during a basal diet period
[b] significant
BD = Basal diet: CD = Challenging diet

Table 9.

Food parameters during cross over periods for DIT assessment (n = 12 ; group 3). Results are expressed as mean values ± SD.

	Cross-over periods		
	BD	**CD**	**p-value** (BD *vs* CD)
Energy Intake*: *Kcal*	161.0 ± 12.3	219.9 ± 13.0	0.809§
Carbohydrates: *%*	61.1 ± 6.6	45.5 ± 12.2	0.403§
Lipids: *%*	28.5 ± 10.3	42.3 ± 11.1	0.878§
Proteins: %	10.4 ± 6.4	12.2 ± 5.9	0.911§

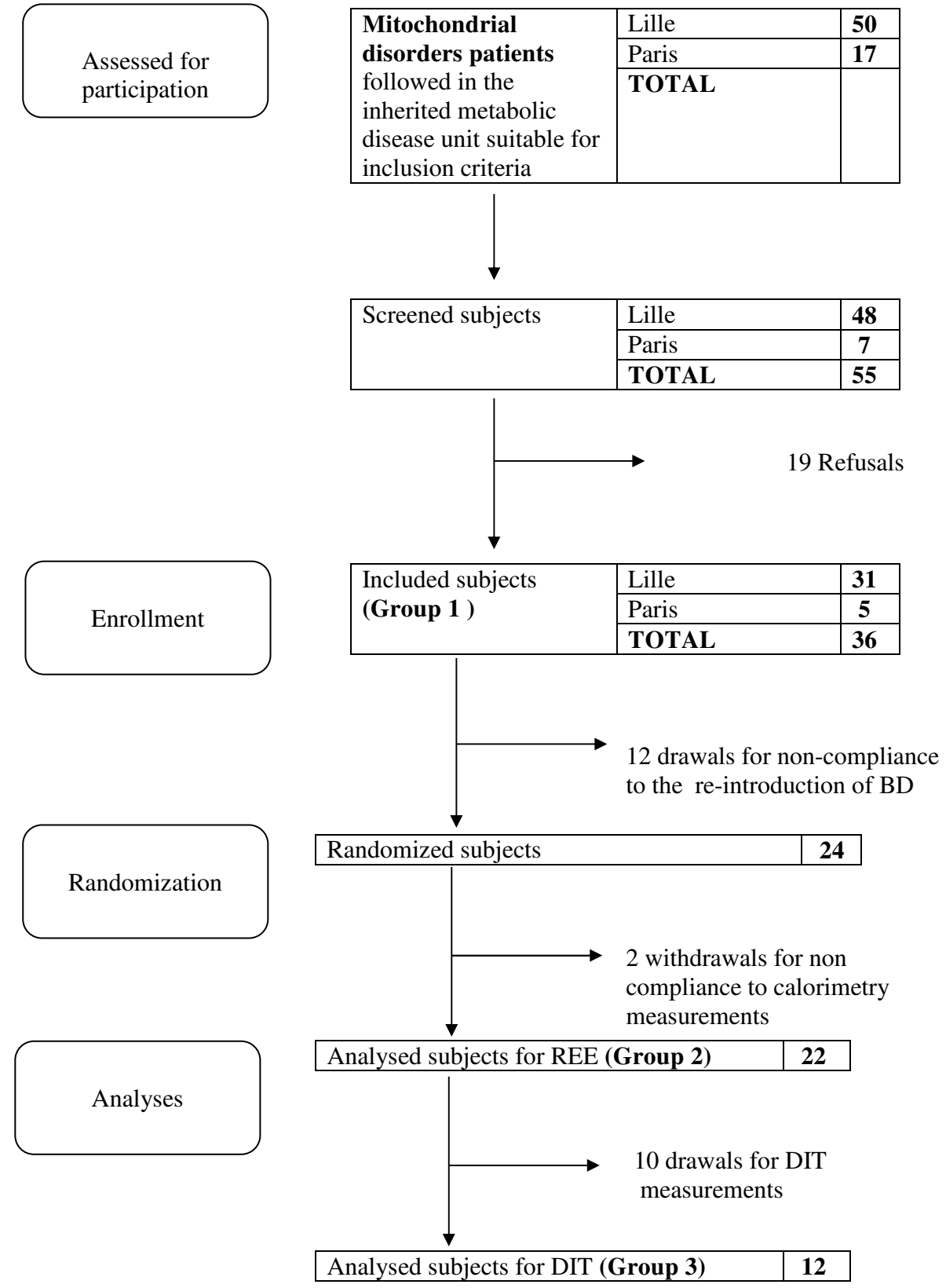
*Energy intake at breakfast for DIT measurement
§ = Wilcoxon test
BD = Basal diet
CD = Challenging diet

Figure 1 : Flow CONSORT diagram of screening, inclusion, randomisation and analysis rate in the study.

Figure 2 : Randomized cross-over design of the study.

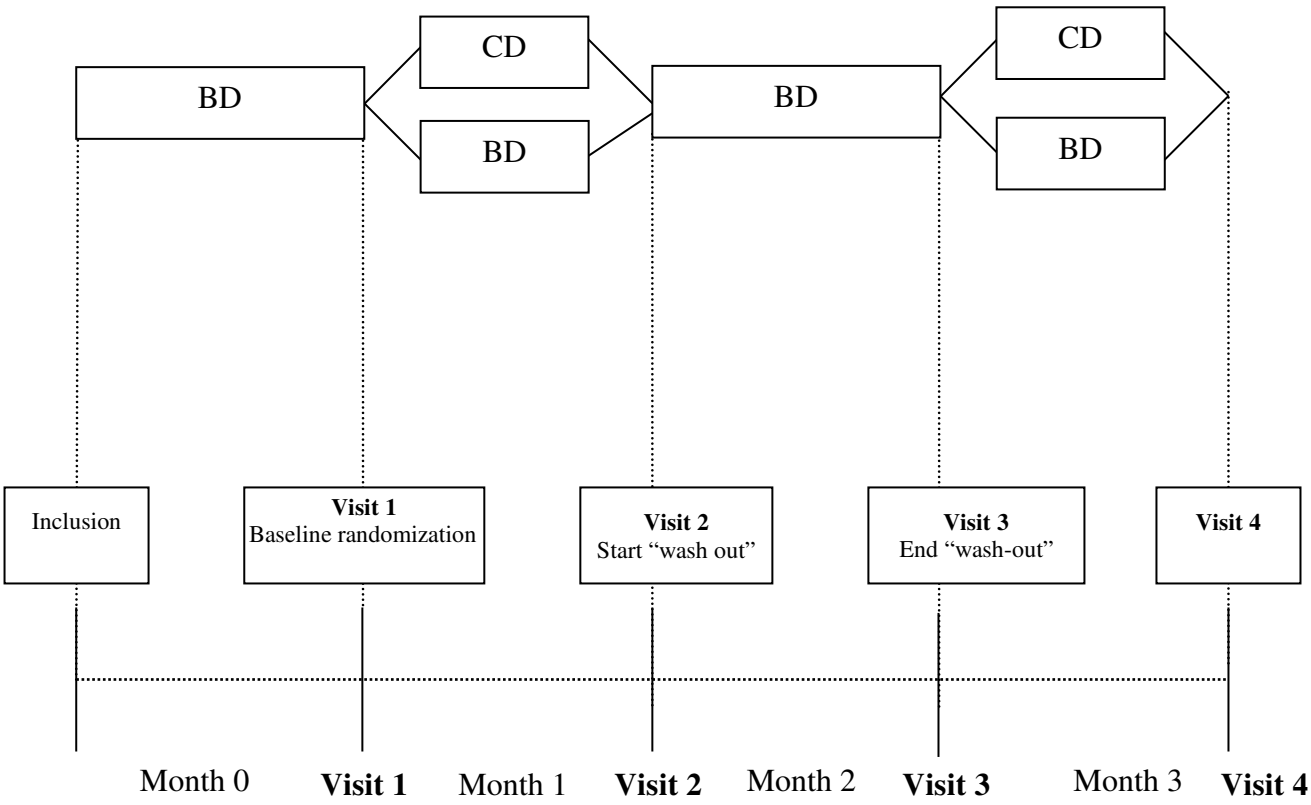
Figure 3 : Evolution of diet induced thermogenesis (only group 3 ; n=12)

Figure 4 : Evolution of RQ during diet induced thermogenesis assessment (only group 3 ; n=12)



BD = Basal Diet
REE = Resting Energy Expenditure
DIT = Diet Induced Thermogenesis

Figure 1 : Flow CONSORT diagram of screening, inclusion, randomisation and analysis rate in the study.



BD = Basal Diet
CD = Challenging Diet

Figure 2 : Randomized cross-over design of the study.

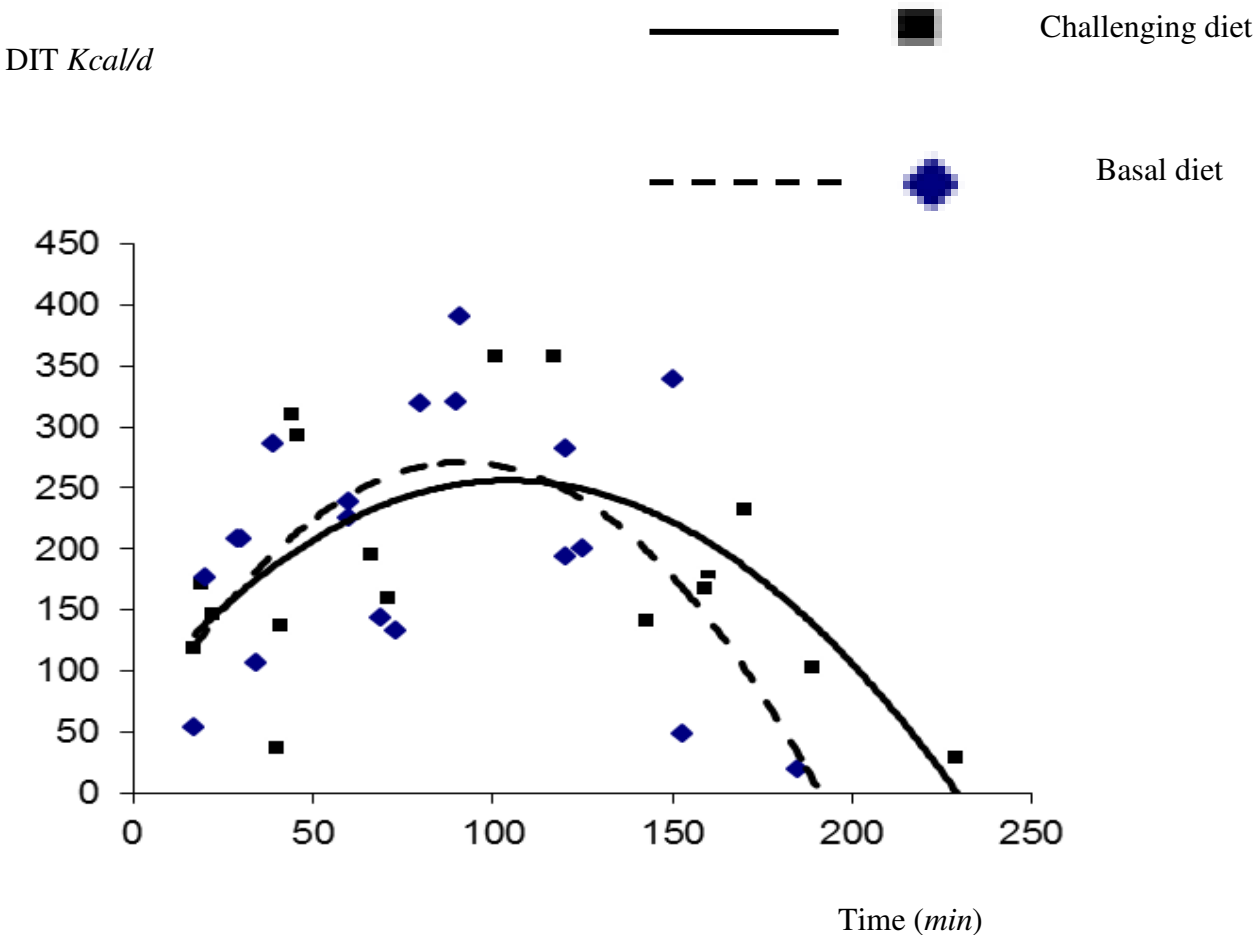


Figure 3 : Evolution of diet induced thermogenesis (only Group 3 ; n=12)

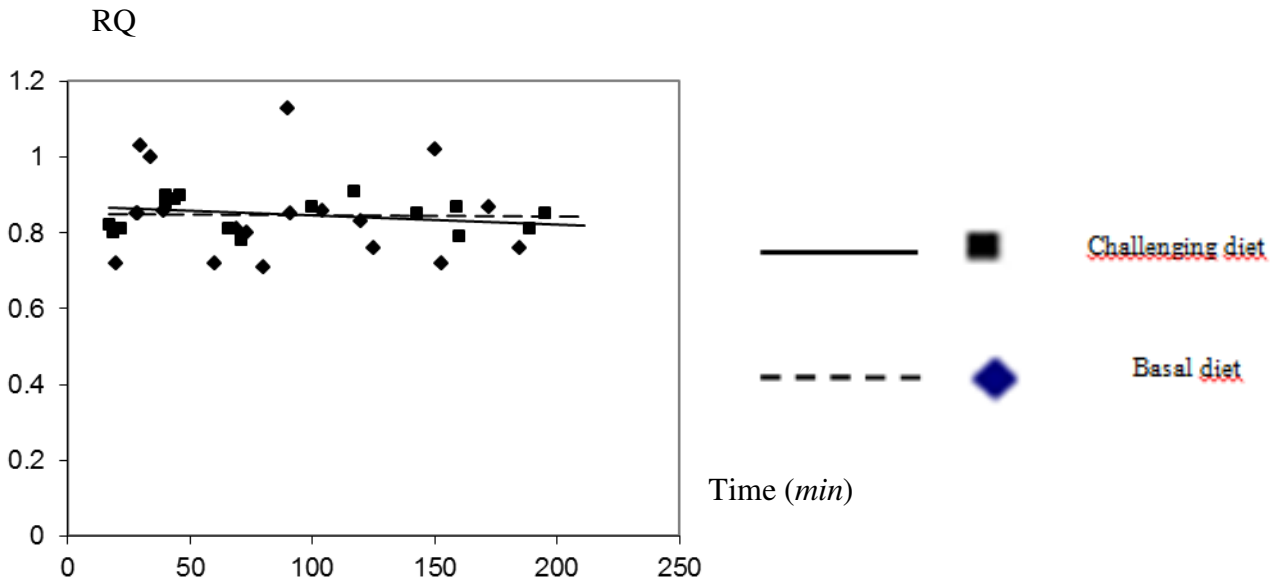


Figure 4 : Evolution of RQ during diet induced thermogenesis assessment (only group 3 ; n=12)