Basal and Resting Metabolic Rates of Physically Disabled Adult Subjects: A Systematic Review of Controlled Cross-Sectional Studies

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Key Words

Physical disability · Energy metabolism · Resting metabolic rate · Indirect calorimetry · Basal metabolic rate

Abstract

Aim: To systematically review studies that investigated the basal metabolic rate (BMR) and resting metabolic rate (RMR) of physically disabled adult subjects. **Methods:** The studies were identified via MedLine, Science Direct, Science Search, Scientific Electronic Library Online, Wiley, Latin American and Caribbean Health Sciences Literature, Cochrane, Índice Bibliográfico Espanol de Ciencias de la Salud, Scopus, ProQuest Dissertations & Theses Database and System for Information on Grey Literature in Europe. No restriction on publication date was imposed. **Results:** Data from 6 studies were included. The results showed that physically disabled adult subjects have a lower BMR and/or RMR compared to nondisabled subjects. However, the difference between the groups disappeared when the BMR and RMR were adjusted for fat-free mass. Due to the small number of studies on this subject and the limited types of physical disabilities evaluated in the literature, we could not make a definitive conclusion.

Conclusions: Disabled individuals seem to have a lower absolute BMR and/or RMR than able-bodied adults; however, this difference was not present or else it disappeared in half of the studies, after adjusting for body mass and/or fat-free mass.

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Introduction

Physical disabilities result from the impairment or inactivity of the locomotor system [1]. Lesions affecting the lower extremities can alter walking patterns. In addition, physical disabilities may cause metabolic alterations, especially if ambulatory aid is required.

Paralyzed muscles cause alterations in body composition, such as increased fat mass (FM) and lower fat-free mass (FFM). Changes in body composition and physical

This work was conducted at the Josué de Castro Nutrition Institute and the Physical Education and Sports School of the Rio de Janeiro Federal University.

Table 1. Search strategies used in PubMed and Scopus database

PubMed	Scopus
<p>Search (Energy metabolism*[All Fields]) OR (Basal metabolism[All Fields]) OR (Resting metaboli*[Text Word]) OR (Energy expenditure*[Text Word]) OR (Resting energy expenditure[Text Word]) OR (Basal energy expenditure[Text Word]) OR (Basal metabolic rate*[Text Word]) AND (Amputee*[All Fields]) OR (Disabled person[All Fields]) OR (Meningomyelocele[All Fields]) OR (Paraplegia[All Fields]) OR (Poliomyelitis[All Fields]) OR (Spinal cord injur*[All Fields]) OR (Spinal dysraphism[All Fields]) OR (Wheelchair*[All Fields]) OR (Amputation[Text Word]) OR (Handicapped[Text Word]) OR (Physical disability[Text Word]) OR (Polio[Text Word]) OR (Spina bifida[Text Word]) OR (Spinal cord lesion[Text Word]) AND (Indirect calorimetr*[All Fields]) OR (Calorimetr*[All Fields]) OR (Oxygen consumption[All Fields]) OR (Respiration calorimetr*[Text Word]).</p> <p>Limits used: humans, adult: 19–44 years and middle-aged: 45–64 years.</p>	<p>ALL (Energy metabolism*) OR ALL (Basal metabolism) OR TITLE-ABS-KEY (Resting metaboli*) OR TITLE-ABS-KEY (Energy expenditure*) OR TITLE-ABS-KEY (Resting energy expenditure) OR TITLE-ABS-KEY (Basal energy expenditure) OR TITLE-ABS-KEY (Basal metabolic rate*) AND ALL (Amputee*) OR ALL (Disabled person) OR ALL (Meningomyelocele) OR ALL (Paraplegia) OR ALL (Poliomyelitis) OR ALL (Spinal cord injur*) OR ALL (Spinal dysraphism) OR ALL (Wheelchair*) OR TITLE-ABS-KEY (Amputation) OR TITLE-ABS-KEY (Handicapped) OR TITLE-ABS-KEY (Physical disability) OR TITLE-ABS-KEY (Polio) OR TITLE-ABS-KEY (Spina bifida) OR TITLE-ABS-KEY (Spinal cord lesion) AND TITLE-ABS-KEY (Indirect calorimetr*) AND TITLE-ABS-KEY (Calorimetr*) AND TITLE-ABS-KEY (Oxygen consumption) AND TITLE-ABS-KEY (Respiration calorimetr*).</p>

inactivity are highly prevalent in disabled individuals, so this population is predisposed to obesity and obesity-related diseases, most notably cardiovascular diseases [2]. The FM has a low metabolic rate whereas the FFM is metabolically active. Therefore, increased FM and reduced FFM are also closely related to decreases in the basal metabolic rate (BMR) and resting metabolic rate (RMR) [3]. It seems likely that the daily energy requirements of disabled patients' differ from those of able-bodied individuals [4]. For nutritional assessment, information on energy expenditure is essential. This expenditure depends on the BMR, physical activity and thermic effect of food [5], with the BMR being the highest contributor, accounting for 60–75% of the daily energy expenditure [6]. Specific nutritional recommendations for people with spinal cord injuries are limited [7], and this information is even rarer for people with other kinds of physical disabilities. Such information is valuable for dietitians to be able to establish rational guidelines for the average energy needs of this population [4].

The purpose of this review was to investigate controlled, cross-sectional studies that evaluated the BMR and/or RMR of adults with physical disabilities.

Methods

The methods for article selection and inclusion criteria were based on the procedures for systematic reviews produced by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [8].

Eligibility Criteria

We evaluated controlled, cross-sectional studies on the BMR and/or RMR of physically disabled subjects. Our review was limited to studies using calorimetry as the method for determining the BMR and/or RMR but no limits regarding publication date. It was restricted to studies on adult and middle-aged human subjects.

Individuals with physical disabilities, such as paraplegia, poliomyelitis, amputation, and spina bifida were considered. Only those studies that recruited an able-bodied control group were included. Studies that involved tetraplegic individuals only, studies with no control group, intervention studies, validation studies, case studies, Letters to the Editor and review articles were excluded.

Electronic databases and article reference lists were used to identify the literature eligible for this review. The following electronic databases were consulted: MedLine, Science Direct, Science Search, Scientific Electronic Library Online (SciELO), Wiley, Latin American and Caribbean Health Sciences Literature (LILACS), Cochrane, Indice Bibliográfico Español de Ciencias de la Salud (IBECS), Scopus, ProQuest Dissertations & Theses Database and System for Information on Grey Literature in Europe (SIGLE). The most recent search was on 28 August 2013.

Descriptors were selected using the MeSH database. The following expressions were used: energy metabolism, basal metabolism, resting metabolism, energy expenditure, resting energy expenditure, basal energy expenditure, basal metabolic rate, amputee, disabled person, meningomyelocele, paraplegia, poliomyelitis, spinal cord injury, spinal dysraphism, wheelchair, handicapped, physical disability, spina bifida, spinal cord lesion, indirect calorimetry, calorimetry, oxygen consumption and respiration calorimetry.

The search strategies used in PubMed and the Scopus database are presented in table 1. Some of the articles described in this review used similar methods but used different terms to define the BMR and RMR. To avoid debate about differences concerning protocols and terms, we named all measurements as the authors did. When the article described both metabolic rates, these values were considered and presented. For this reason, BMR and RMR were the terms used in this review.

	Bargieri [28] 2008 (Brazil)	Bertoli [29] 2006 (Italy)	Bauman [27] 2004 (USA)	Buchholz [9] 2003 (Canada)	Monroe [26] 1998 (USA)	Alexander [25] 1995 (USA)
<i>Population of the study</i>						
Eligibility criteria of participants	(+)	(+)	(-)	(+)	(-)	(+)
Gender	(+)	(-)	(-)	(-)	(+)	(+)
Kind of disability	(+)	(-)	(-)	(+)	(-)	(+)
Lesion level and classification	(+)	(?)	(-)	(-)	(+)	(+)
<i>Data sources/measurements</i>						
RMR protocol	(+)	(+)	(+)	(?)	(+)	(?)
Equipment (calibration)	(+)	(-)	(+)	(+)	(+)	(+)
Evaluation of body composition	(+)	(+)	(+)	(+)	(+)	(-)
Statistical methods	(+)	(+)	(+)	(+)	(?)	(+)
Study size	(-)	(-)	(-)	(-)	(-)	(-)
Reliable results	(+)	(?)	(+)	(+)	(+)	(?)
<i>Discussion</i>						
Limitations	(-)	(-)	(-)	(+)	(+)	(+)
Interpretations	(?)	(+)	(+)	(+)	(+)	(+)
Generalizability	(+)	(+)	(+)	(+)	(+)	(+)

Fig. 1. Summary of the risk of bias. (+) 'Yes' – low risk of bias; (-) 'No' – high risk of bias; (?) 'Unclear'.

Data Extraction

Data from the selected studies were extracted by one researcher and checked by another based on the standardized forms developed for this review.

We aimed to evaluate the BMR and/or RMR of physically disabled individuals in comparison to able-bodied subjects, so we extracted information about both these populations and divided the data into 2 groups: the disabled group (DG) and the control group (CG). Only data regarding BMR and/or RMR and body composition were used, even when the study researched different groups and outcomes. Numerical variables were presented as the mean $\pm$ standard deviation.

Any unpublished information about the body mass index (BMI), FM in kilograms, BMR and/or RMR adjusted for body mass (BM) or FFM used in the results of the original studies was requested from the original investigators, but only one [9] sent any extra material.

Assessment of Bias Risks

To ascertain the validity of the eligible controlled cross-sectional studies, a pair of reviewers developed a checklist based on the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations [10]. Not all of the STROBE items were considered as some are for domain-based evaluations,

and the checklist was adapted to our study. In this review, we evaluated only information regarding the studied population, data sources/measurements, possible bias and individual questions about the objectives, results and discussions that we thought were extremely important to our final conclusions (fig. 1). The answer 'Yes' indicated a low risk of bias, 'No' indicated a high risk of bias and 'Unclear' indicated either a lack of information or uncertainty about the potential for bias. The same pair of reviewers independently determined the adequacy of the selected variables. Based on the potential bias risks found, we selected some of the most relevant criteria and summarized them in table 2.

Results

The first database search retrieved 1,795 articles, and 2 more articles were identified from the reference lists. After removing duplicates ($n = 1,092$), 705 articles remained, and these were screened based on their titles. Of the remaining articles, 647 were excluded because they did not follow the criteria imposed by the review or did

Table 2. Criteria for judging the risk of bias

Type of bias	Description	Review of the authors' judgement
<i>Study population</i> Eligibility criteria of participants	gives the eligibility criteria and the source and means of participant selection	Yes – specified the participant selection and eligibility criteria No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Gender	specifies the gender and if both were included, whether they are presented as 2 separate groups	Yes – divided gender in specific groups No – did not divide gender in specific groups Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Type of disability	specifies the type of disability studied	Yes – specified what types of disabilities were present No – did not specify what types of disabilities were considered as a single group Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Lesion level and classification	specifies the location and classification of the injury or lesion	Yes – specified the location, completeness and, if possible, the classification of the injury or lesion No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
<i>Data sources/measurements</i> RMR protocol	specifies the measurement protocol chosen to evaluate the RMR	Yes – described the RMR measurement protocol No – the protocol used was not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No' or for reproducing the protocol
Equipment (calibration)	specifies the equipment calibration	Yes – specified whether the equipment was routinely calibrated No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Evaluation of body composition	provides information about the body composition of the individuals evaluated	Yes – evaluated the body composition of the participants No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Statistical methods	specifies all of the statistical methods used and whether they were in agreement with the stated objectives	Yes – described the statistical methods and whether they were sufficient for achieving the objectives No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Study size	the sample size was sufficiently large	Yes – a large number of participants No – a small number of participants Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Selection of relevant results	presents results relevant to the reference objectives	Yes – selection of participants and eligibility criteria specified No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Reliable results	presents key results that reference the study objectives	Yes – presented key results that reference the study objectives No – did not present key results that reference the study objectives Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'

Table 2. (continued)

Type of bias	Description	Review of the authors' judgement
<i>Discussion</i>		
Limitations	discusses the limitations of the study and accounts for sources of potential bias and imprecision, including both the direction and magnitude of any potential bias	Yes – specified the limitations of the study No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Interpretations	provides a cautious overall interpretation of the results, considering the objectives, limitations and multiplicity of the analyses, results from similar studies and other relevant evidence	Yes – provided a cautious overall interpretation of the results No – information not provided Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'
Generalizability	discusses the generalizability (external validity) of the study results	Yes – discussed the generalizability of the study results No – generalizability not discussed Unclear – insufficient information to allow for a judgment of either 'Yes' or 'No'

Fig. 2. Flow diagram of the study selection process. SCI = Spinal cord injury.

not address the required issues. Fifty-eight articles remained, 35 of which were excluded after reading the abstracts. The remaining 23 articles were read in full. Seventeen articles were excluded from the systematic review after the full reading. Ten of these did not compare the disabled subjects to able-bodied subjects [2, 4, 11–18], 2

were review articles [7, 19], 1 presented data from a non-adult population [20], 1 examined tetraplegia only [21], 2 were influenced by acute effects [22, 23] and 1 evaluated the cost of ambulation only [24].

We ultimately included 6 studies (fig. 2; table 3). They were all controlled, cross-sectional studies published in

Table 3. Summary of the included studies evaluating the differences in BMR and/or RMR between physically disabled and able-bodied adults

First author, year (country)	N	Age, years	PD	Methods	BMI, kg/m ²	FM, %	FFM, kg	RMR, kcal/day	RMR/BM, kcal/kg	RMR/FFM, kcal/kg	Conclusion
Bargieri, 2008 (Brazil) [28]	DG: 16 CG: 18	DG: 47.5±7.5 CG: 41.6±10.8	PPS	IC DXA	DG: 24.5±3.3 CG: 26.0±3.1	DG: 24.0±7.4 CG: 22.2±6.0	DG: 53.2±8.7 CG: 63.2±6.0*	DG: 1,396±364 CG: 1,609±288*	DG: 19.8±3.5 CG: 19.7±2.6 ^a	DG: 26.1±4.1 CG: 25.5±4.2	BMR was lower in PPS individuals, but the difference disappeared when adjusting for BM and FFM
Bertoli, 2006 (Italy) [29]	DG: 24 CG: 25	DG: 37.6±6.7 CG: 31.0±9.3	PARA POLIO	IC DXA	DG: 25.2±4.0 CG: 25.3±2.3	DG: 34.1±9.1 CG: 20.6±8.8*	DG: 45.8±8.3 CG: 51.5±9.1*	DG: 1,550±309 CG: 1,794±308*	DG: 20.2±2.6 CG: 24.0±3.6*	DG: 34.2±6.1 CG: 35.4±2.6	Absolute RMR was lower in disabled subjects, but the difference disappeared when RMR was normalized to FFM
Bauman, 2004 (USA) [27]	DG: 13 CG: 13	DG = CG: 37.0±8.0	C PARA I PARA	IC DXA	DG: 22.7±4.0 CG: 24.4±3.5*	NI	DG: 45.6±10.0 CG: 55.5±11.9*	DG: 1,682±388 CG: 1,854±376*	DG: 24.9±5.4 CG: 24.2±4.1	DG: 36.9 CG: 33.4 ^a	BMR and RMR were lower in the twins with SCI and both were related to FFM that was lower in this group
Buchholz, 2003 (Canada) [9]	DG: 28 CG: 34	DG: 33.9±9.2 CG: 29.1±7.6*	C PARA I PARA	IC TBW	DG: 24.3±6.0 CG: 23.5±1.8	DG: 30.8±8.7 CG: 22.8±7.2*	DG: 45.3 CG: 54.6*	DG: 1,472±228 CG: 1,677±223*	DG: 22.5 CG: 23.7 ^a	DG: 32.5 CG: 30.7 ^a	RMR was lower in chronic PARA but did not differ between paraplegic and able-bodied subjects after adjustment for FFM
Monroe, 1998 (USA) [26]	DG: 10 CG: 59	DG: 35.5±8.0 CG: 31.9±7.1	C PARA C TETRA	RC DXA	NI	DG: 23.0±12.0 CG: 26.0±10.0	DG: 51.6±6.8 CG: 64.1±9.0*	DG: 1,755±64 CG: 2,211±317*	DG: 25.4 CG: 24.6 ^a	DG: 34.01 CG: 34.49 ^a	RMR was lower in SCI subjects than in controls, even after adjusting for FFM, FM and age
Alexander, 1995 (USA) [25]	DG: 24 CG: 23	DG: 50.0±3.0 CG: 54.0±3.0	C PARA I PARA	IC	DG: 26.1±1.0 CG: 26.7±1.1	NI	NI	DG: 1,780±62 CG: 1,751±55	DG: 21.4±0.6 CG: 22.5±0.4	NI	There were no significant difference between measured RMR of NPS-PARA and CG

C = Complete; DXA = dual X-ray absorptiometry; I = incomplete; IC = indirect calorimetry; N = number of patients; N/A = not available; NPS = no pressure sores; P = population; PARA = paraplegia; PD = physical disability; POLIO = poliomyelitis; PPS = post-polio syndrome; RC = respiratory chamber; SCI = spinal cord injury; TBW = total body water; TETRA = tetraplegia. * $p < 0.05$, significant difference between DG and CG.

^a Result of BMR.

English between 1995 and 2008. Most of them were conducted in the USA [25–27], and there was 1 study each from Canada [9], Brazil [28] and Italy [29]. Four of the studies analyzed subjects with spinal cord injuries only [9, 27–29], 1 evaluated spinal cord lesions and poliomyelitis impairment [29] and 1 evaluated patients with post-polio syndrome [28]. Three [9, 27, 29] included both male and female subjects, and the other 3 involved only male subjects.

The total number of physically disabled individuals evaluated was 115 (96 males). The primary disability was spinal cord injury, and there were 88 paraplegics and 3 tetraplegics. Spina bifida was the cause of paraplegia in 4 individuals. Sixteen of the 24 participants with poliomyelitis had post-polio syndrome, which is a neurological

disorder that develops between the ages of 15 and 20 after acute paralytic poliomyelitis [30, 31]. The sample sizes ranged from 10 to 28 individuals for the disabled subjects. For the able-bodied subjects, there was a total of 172 individuals (158 males), and the sample sizes ranged from 13 to 59. The studies analyzing tetraplegic patients in the same group as the paraplegic patients were included in this review either because the patients presented with high functionality that allowed them to perform their own transfers and daily activities and they could use manually propelled wheelchairs [26], or because there were only a few individuals with incomplete lesions [27].

Alexander et al. [25] used a metabolic chart to determine the RMR by analyzing the air exhaled from paraplegic men both with ($n = 14$) and without ($n = 24$) pres-

sure sores and 23 individuals without spinal cord injuries who were in good health [the results presented are only from the DG without pressure sores ($n = 24$)]. The authors noted that the percent of predicted RMR was lower in the DG than in the CG. Monroe et al. [26] measured the energy expenditure and BMR of 10 males with spinal cord injuries and 59 age-matched controls. There were no significant difference between the DG and CG in terms of height or %FM, but the CG was significantly heavier than the DG (89.9 ± 23.6 and 70.1 ± 17.2 kg, respectively). Furthermore, the DG had a lower energy expenditure than the CG, both in the absolute analysis and after adjusting for BM and/or FFM. Buchholz et al. [9] measured the RMR of 28 paraplegic and 34 control subjects matched according to BMI. The results showed that the RMR was significantly higher (by 14%) in the CG than in the DG, and this difference remained significant even after adjusting separately for age, weight and FM. However, this difference was reduced to <2% after adjusting separately for FFM ($p = 0.5467$), FM and FFM together ($p = 0.3692$) and body cell mass ($p = 0.5780$). Similar results were obtained when the groups were divided by sex. Bauman et al. [27] aimed to investigate the relationship between energy expenditure and FFM in 13 pairs of twins discordant for spinal cord injury. Those with spinal cord injuries had a significantly lower BM, BMI and body surface area than the CG. The measured BMR and RMR were significantly lower in the DG than in the CG; however, when adjusted for BM, the differences disappeared. Bertoli et al. [29] compared patients with physical disabilities only ($n = 24$) with a CG of 25 individuals. In contrast with the results of Bauman et al. [27], the measured RMR values were significantly lower in the DG than in the CG ($p < 0.01$) even after adjusting for BM. The difference only disappeared when it was normalized for FFM. The most recent study identified, by Bargieri et al. [28], aimed to compare the BMR of patients with post-polio syndrome to healthy individuals. Sixteen male patients with post-polio syndrome were recruited in the DG along with 18 healthy male individuals who served as the CG. The DG were thinner (a mean difference of 11.1 kg) and shorter (a mean difference of 8.1 cm). The BMR absolute values were lower in the DG but no difference was found when it was adjusted for BM and FFM.

In the studies analyzed, the BMR ranged between 1,387 and 1,660 and the RMR ranged between 1,472 and 1,854 kcal in the DG and CG, respectively. The majority of studies ($n = 5$) found significant differences between the BMR and/or RMR of the 2 groups [9, 26–29]. The BMR and/or RMR values were lower for the disabled subjects when ex-

pressed in absolute values; however, when adjusted for the FFM, this difference disappeared in half of the studies. Monroe et al. [26] found that a significant difference remained between the 2 groups after adjusting for the FFM. Alexander et al. [25] did not find any significant differences between the RMR of the DG and the CG (table 3).

The risk of bias in the individual studies is detailed in figure 1. The main problems were the sample sizes, the limited number of physical disabilities and the lesion level. Another limitation in most of the studies was the inclusion of both genders in the same sample.

Discussion

In this systematic review, we found that although few controlled studies analyzed the basal or resting metabolism of disabled subjects, the results suggest that this metabolism is low in the disabled population compared to the control subjects. However, after adjusting the metabolism for BM and/or FFM, the difference seems to disappear.

Of the 5 studies that evaluated subjects with spinal cord injuries, only that by Alexander et al. [25] showed no significant differences between the absolute measured RMR and RMR/kg BM for the DG and CG. The authors did not consider the length of time since injury, a factor that may have influenced this result. This factor may influence body atrophy, especially in the legs, and the loss of lean tissue mass, which thereby affects the RMR. Both the degree of the injury and whether it is complete or incomplete are also important issues that influence the physical independence, mobility and activity of patients.

In Monroe et al. [26], the lower-energy metabolism of the DG was independent of the BM and body composition differences. The sympathetic nervous system was postulated to have an important influence on the RMR, in addition to physical inactivity and body composition. A reduction in peripheral sympathetic nervous system activity caused by the interruption of the pathways from the brain to the peripheral sympathetic nervous system may reduce the overall metabolic rate [21, 32, 33].

Buchholz et al. [9] found no significant correlation between the onset of paraplegia, which may influence the body composition, and FFM. As in the other studies analyzed, the RMR was lower for the DG relative to the CG; however, this difference was no longer found after adjusting for FFM. The FFM was the best single predictor of the RMR, and it accounted for 83% of the variation in the RMR in the CG ($p < 0.0001$) and for 70% of the variation in the DG ($p < 0.0001$).

Bauman et al. [27] and Bertoli et al. [29] also found lower BMR and/or RMR values for the DG in comparison to the CG. Bertoli et al. [29] found that the RMR was significantly lower for the DG than the CG ($p < 0.01$) even after normalizing for BM; however, these differences disappeared after normalizing for the FFM. In contrast, the results of Bauman et al. [27] indicated that the difference between groups was maintained after normalizing for FFM but not for BM.

Despite the small number of studies evaluating the absolute values of BMR and/or RMR in disabled subjects, it seems, at this time, that these variables were lower in subjects with spinal cord injuries than in able-bodied individuals. Decreased physical activity after spinal cord lesion results in substantial changes in muscle mass, bone minerals and body fat [34] but may not significantly alter BM. When studies adjusted the DG and CG values for age, height and weight, the groups had similar BMIs, but dissimilar body compositions [35, 36].

Poliomyelitis impairment and post-polio syndrome are other types of disabilities that cause physiological changes. Bertoli et al. [29] analyzed the subjects with spinal cord injury and poliomyelitis subjects as a single group and did not consider their physiological differences. It seems that both groups have lower BMR and RMR values. Moreover, the group with spinal cord injuries showed lower FFM and reduced sympathetic nervous system activity in some studies [21, 32]; however, in another study [2], these values were not actually lower. Muscle atrophy in poliomyelitis patients may not be caused by chronic wheelchair use but by the disease itself. The use of crutches by individuals with poliomyelitis and post-polio syndrome influences the limbs used for ambulation and thus affects muscle mass, physical activity, body composition, BMR and RMR.

Bargieri et al. [28] unexpectedly found no difference in the %FM between the DG and CG. However, the height, BM and body surface area of the subjects were significantly different between groups and there were even differences in BMI, with the DG classified as eutrophic and the CG classified as overweight. Individuals with post-polio syndrome were approximately 10 kg thinner and 8 cm shorter than the CG, and they had lower BMI and FFM values than the CG, but both groups had a similar %FM. Most likely, if the anthropometric characteristics of the groups were similar, there would be a difference in their %FM.

Chang et al. [37] evaluated the changes in both the total and regional body FM by dual X-ray absorptiometry as well as the clinical usefulness of the BMI for detecting overweight poliomyelitis subjects. This study included 18

middle-aged individuals with a mean age of 47 years, which is similar to those enrolled in the study by Bargieri et al. [28]. The average duration since diagnosis was 45.4 years. A control group matched by sex, age, BM and height were also recruited ($n = 18$). In each group, 12 men and 5 women completed the study. All of the individuals with poliomyelitis had flaccid paralysis of one or both of the lower extremities. The DG had a higher total %FM and FM values in every region of the body than the CG, showing that poliomyelitis subjects have a higher prevalence of obesity. Therefore, the DG is at a greater risk of developing cardiovascular diseases than the CG.

We did not find any studies that analyzed the BMR and/or RMR of amputee subjects that considered the different levels of amputation, especially of the lower body parts, which are the most likely to influence the BMR and RMR. Previous studies showed that ambulation with crutches was less energy-efficient than walking normally [18, 38–40]; however, we do not know if the loss of one or both of the lower extremities beneath the knee may alter the BMR and RMR. We speculate that amputation of a lower extremity may alter the metabolism of an individual because of the reduced FFM as well as potential chronic wheelchair use; however, the metabolism in individuals with bilateral, transtibial or transfemoral amputations would be different. Moreover, the metabolism of individuals would differ according to whether the ambulatory aids used were prosthetics or crutches.

When discussing paraplegia, poliomyelitis and amputation, we should be aware of the cause of the disease. There are most likely differences for patients with life-long paraplegia, such as spina bifida, compared to patients whose paraplegia was caused by trauma later in life, such as a car accident. When someone spends their entire life in a wheelchair, their body composition and metabolism would be different from individuals who have experienced a trauma. The cause of disability would have different effects on body composition, physical activity, basal and resting metabolism, nutritional requirements and cardiovascular disease. Therefore, the cause of disability is an important variable that must be analyzed. Furthermore, the length of time since the beginning of the physical deficiency, considered by Buchholz et al. [9] and Bauman et al. [27], and the localization of the lesion, which varied between the studies, should also be considered because these factors could influence body composition and the BMR/RMR.

In assessing the bias risk, we identified some limitations in the studies that we reviewed. Some included male and female subjects but did not analyze them separately [9, 27, 29]; this can introduce bias because of differences

between the BMR, RMR and body composition values of males and females. The hormonal variations in females during menstruation and ovulation can influence metabolism [41]. Therefore, any results that did not separately evaluate male and female subjects may have introduced a possible confounding effect.

The location and completeness of a lesion determine the degree of physiological system impairment, explaining why paraplegic individuals are more independent and mobile and have better-preserved physiological systems than tetraplegic patients. The RMRs of these 2 groups should not be analyzed together as they were in the studies by Monroe et al. [26] and Bauman et al. [27]. Despite the fact that tetraplegic subjects have a lower RMR than paraplegic individuals [4], we kept these 2 studies in our analysis because the tetraplegic patients included were in the minority [26, 27] and they presented high functionality, i.e. they were capable of performing transfers and daily activities on their own [26]. The poliomyelitis sequelae result in different body composition based on whether one or both legs have been affected [37], and this factor also influences the ambulatory aid required. Study authors should consider these characteristics when describing a population and when analyzing and discussing the results.

Another limitation of the reviewed studies was the small sample size and limited range of disability actually

studied. We understand how difficult it is to find disabled volunteers to enroll in these studies, as in the study on monozygotic twins by Bauman et al. [27].

Conclusions

In this review, 6 studies were found on BMR and RMR in physically disabled adult subjects with spinal cord injury and poliomyelitis. The majority of studies showed that individuals with spinal cord injury, poliomyelitis and post-polio syndrome have lower absolute BMR and/or RMR than able-bodied adults; however, this difference was not present or it disappeared in half of the cases, when adjusting for BM and/or FFM. In future studies, efforts should be made to develop equations to calculate BMR/RMR in this group of patients, based on measured FFM, because indirect calorimetry is not available for use in daily practice.

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