The Effects of Exercise Training on Fat-Mass Loss in Obese Patients During Energy Intake Restriction

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Abstract

Dietary restriction combined with endurance exercise training represents an effective strategy to promote weight loss and reduce fat mass in obese patients. Exercise programmes without dietary restriction are less efficient. However, addition of exercise to a dietary restriction programme does not induce a greater fat-mass loss than dietary restriction alone. The latter is likely attributed to a compensatory reduction in daily physical activity following the implementation of exercise training. Nonetheless, inclusion of an exercise training programme is important to prevent a decrease in fat-free mass, increase relative visceral fat-mass loss, improve dietary compliance and eventually maintain long-term weight control. Obese male patients with the highest fat mass are most likely to lose the largest amount of fat mass in such lifestyle intervention programmes. Influences
of training modalities during energy intake restriction on fat-mass loss are reviewed. The relationship between total energy expenditure during exercise training and overall fat-mass loss has been firmly established. The amount of training forms a more important predictor of fat-mass loss than training intensity. The sort of exercise (e.g. walking, cycling, swimming) plays another important predictor of fat-mass loss in intervention programmes. The implementation of resistance training in such programmes does not augment fat-mass loss but improves body composition by increasing fat-free mass. Further studies are needed to define the optimal interventional programme for obese patients.

In the past two decades, the world has experienced an increased prevalence of obesity, resulting in a global obesity epidemic.[1,2] A key reason behind this epidemic is the lack of daily physical activity and food abundance. Our genome was probably selected in the late Palaeolithic period (50 000–10 000BC) from criteria that favoured survival in a physically demanding environment, such as our ancestor’s hunter and gatherer society. Fluctuations between feast and famine was not unusual, resulting in oscillations in endogenous fuel storage, plasma insulin and metabolic regulatory proteins, which in turn may have driven a selection of a metabolic genotype optimal for such conditions. The ‘thrifty genes’ theory states that these feast-famine cycles are required for optimal metabolic function.[3,4] Those individuals in the late Palaeolithic period who were capable of converting calories into adipose tissue and easily stored fat during feasting, were likely to have had a higher survival rate during famine and were capable of passing their genes on to the next generation.[5] It might be the case that many individuals of our modern society are carriers of this thrifty genotype. Therefore, overfeeding in combination with a sedentary lifestyle, as seen in the modern era, could be responsible for the increased prevalence of devastating consequences such as obesity and type 2 diabetes mellitus.

In addition to increasing overall mortality, obesity is closely linked to the development of hypertension, type 2 diabetes, dyslipidaemia, gallbladder disease, osteoarthritis, coronary heart disease, stroke, sleep apnoea and other respiratory problems.[6] At present, various therapeutic interventions, such as diet and food intake modification, exercise training interventions, surgical modification of the gastro-intestinal tract, liposuction and medication, have become available to the obese patient.[7,8] In the first line of medical intervention, most patients will be offered an exercise and/or dietary intervention programme. In such a lifestyle intervention programme, two main goals are formulated: (i) weight loss; and (ii) enhanced physical workload capacity. At present, an energy deficit of 500–1000 kcal/day is recommended to induce proper weight loss.[9] This energy deficit should be realised by a combination of dietary restriction and physical exercise. Significant health benefits can be obtained when performing a minimum of 150 minutes of moderate intensity exercise per week (at 55–70% of maximal heart rate capacity), with a progressive increase to 200–300 minutes per week.[9]

The results from combined dietary and exercise intervention programmes on fat-mass loss and exercise capacity suggest a dissociated progress of both outcome measures.[10,11] In other words, fat-mass loss is not always associated with an enhanced exercise capacity and vice versa.[10,21] In this review, we focus on the effects of dietary restriction and exercise training intervention on fat-mass loss and body composition. We also review the influence of different training modalities on the changes in fat mass.

It is important to note that when we refer to ‘fat mass’, we mean ‘adipose tissue mass’. In this review, when mentioning a change in fat mass, we are referring to the content of the fat cell and not the actual number of fat cells. Therefore, with a decline in fat mass, it is the content of the fat cell that declines (referred as ‘adipose tissue mass’), without
a change in the number of adipocytes. This is in clear contrast to the effects of liposuction procedures, where a large number of adipocytes are removed without affecting adipocyte size. Here, we use ‘fat-mass loss’ as a reference to a reduction in adipose tissue mass.

In this review, we selected studies where the subjects were obese (BMI >30 kg/m²), >19 years of age and who were subjected to an intervention programme.

1. Effects of Exercise Training on Fat Mass

In obese patients, fat-mass loss can be effectively achieved by combining dietary restriction with endurance exercise training. Miller et al.\(^22\) state that the average weight loss as a result of 16 weeks of combined endurance exercise and caloric restriction averages ≈11kg. Even without dietary restriction, endurance exercise training effectively lowers bodyweight,\(^{20,23,24}\) although to a lesser extent (on average ≈3kg of bodyweight loss).\(^22\) As such, most data suggest that dietary restriction combined with aerobic exercise training is the most effective strategy to maximise bodyweight loss. But, how much do we know about the real effects of endurance training on fat-mass loss during programmes that combine exercise intervention with caloric restriction?

1.1 Effects of Endurance Training on Fat-Mass Loss During Caloric Restriction

It has been debated to what extent endurance training augments fat-mass loss in obese subjects under dietary restriction. As shown in table I, many studies report that the inclusion of aerobic exercise, in addition to an energy intake restriction programme, does not appear to facilitate fat-mass loss.\(^{10,12,14,16,18,19,23,25-34}\) This is confirmed in a meta-analysis by Miller et al.\(^22\) and only a few studies show otherwise.\(^{35-38}\) It remains to be established which factors are responsible for the apparent contradictory findings, as the body fat assessment procedure, subject age, intervention duration and applied methodology were similar in these studies. Nonetheless, those studies with evidence for additional effects of exercise training on fat-mass loss have the lowest sample sizes, which might question their statistical power.

In table I, it is shown that the duration of the implemented training programme varies considerably between studies. However, both in the short and long-term intervention programmes, additional exercise training did not seem to augment fat-mass loss during caloric restriction. Therefore, both in short- and long-term interventions, it seems unlikely that exercise training promotes fat-mass loss during caloric restriction. As such, other factors might be more important in determining the impact of additional exercise training on fat-mass loss.

Whatley et al.\(^21\) reported an enhanced fat-mass loss following dietary restriction in combination with a training programme with high levels of exercise, as opposed to a training regimen with low levels of exercise, where no enhanced fat-mass loss was detected. This study clearly showed the importance of the amount of endurance training to maximise fat-mass loss. This adds to the apparent contradictory findings in the literature. Given that the amount of caloric expenditure as result of endurance training is of great importance to predict additional fat-mass loss during caloric restriction, it is unfortunate that most studies (see table I) do not mention the caloric expenditure per training session.

Although there seems to be no substantial additional effect of endurance exercise interventions on fat-mass loss in obese subjects under dietary restriction, exercise interventions are associated with other major health benefits. The latter is supported by numerous studies showing improved maintenance of the initial bodyweight loss following combined exercise and dietary intervention, as opposed to dietary restriction alone.\(^22\) However, in this meta-analysis, the therapy compliance was not analysed. This is unfortunate as it has been speculated that compliance to a dietary restriction can be improved by the implementation of exercise training in the interventional programme.\(^38\)

The meta-analysis conducted by Ballor and Poehlman\(^39\) revealed another important effect of exercise training on the changes in fat-free mass as...
Table I. Studies comparing caloric restriction with combined caloric restriction/endurance training: effects of additional endurance training on fat-mass loss

<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Subject characteristics (two groups compared in each study)</th>
<th>Daily caloric expenditure during exercise (kilo calories)</th>
<th>Programme duration (weeks)</th>
<th>Effect of extra training on fat-mass loss during caloric restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean age (years)</td>
<td>mean BMI (kg/m²)</td>
<td>mean % fat</td>
<td>sex</td>
</tr>
<tr>
<td>Ashutosh et al.[14]</td>
<td>46 vs 40</td>
<td>NA</td>
<td>NA</td>
<td>f</td>
</tr>
<tr>
<td>Dengel et al.[10]</td>
<td>61 vs 57</td>
<td>30.1 vs 30.3</td>
<td>30.2 vs 30.1</td>
<td>m</td>
</tr>
<tr>
<td>Dengel et al.[34]</td>
<td>60 vs 58</td>
<td>NA</td>
<td>29.3 vs 29.5</td>
<td>m</td>
</tr>
<tr>
<td>Donnelly et al.[16]</td>
<td>NA</td>
<td>38.2 vs 37.5</td>
<td>47.0 vs 46.6</td>
<td>f</td>
</tr>
<tr>
<td>Donnelly et al.[33]</td>
<td>NA</td>
<td>NA</td>
<td>46.9 vs 46.7</td>
<td>f</td>
</tr>
<tr>
<td>Fox et al.[29]</td>
<td>66 vs 65</td>
<td>29.8 vs 30.6</td>
<td>43.3 vs 42.8</td>
<td>f</td>
</tr>
<tr>
<td>Geliebter et al.[18]</td>
<td>36 vs 36</td>
<td>NA</td>
<td>39.8 vs 41.3</td>
<td>m and f</td>
</tr>
<tr>
<td>Hays et al.[20]</td>
<td>67 vs 65</td>
<td>31.0 vs 30.8</td>
<td>42.1 vs 41.2</td>
<td>m and f</td>
</tr>
<tr>
<td>Hill et al.[34]</td>
<td>37 vs 35</td>
<td>35 vs 36</td>
<td>44.3 vs 44.5</td>
<td>f</td>
</tr>
<tr>
<td>Kempen et al.[27]</td>
<td>37 vs 39</td>
<td>31.7 vs 32.4</td>
<td>41.8 vs 41.6</td>
<td>f</td>
</tr>
<tr>
<td>Lennon et al.[27]</td>
<td>34 vs 31</td>
<td>NA</td>
<td>31.1 vs 29.7</td>
<td>m and f</td>
</tr>
<tr>
<td>Marks et al.[29]</td>
<td>38 vs 39</td>
<td>30.1 vs 28.7</td>
<td>41.5 vs 38.3</td>
<td>f</td>
</tr>
<tr>
<td>Nieman et al.[26]</td>
<td>45</td>
<td>34.2 vs 32.6</td>
<td>44.3 vs 43.3</td>
<td>f</td>
</tr>
<tr>
<td>Pronk et al.[19]</td>
<td>43 vs 44</td>
<td>NA</td>
<td>47.5 vs 46.7</td>
<td>f</td>
</tr>
<tr>
<td>Utter et al.[23]</td>
<td>45 vs 49</td>
<td>34.2 vs 32.6</td>
<td>44.3 vs 43.4</td>
<td>f</td>
</tr>
<tr>
<td>Racette et al.[30]</td>
<td>41 vs 36</td>
<td>NA</td>
<td>44.2 vs 45.0</td>
<td>f</td>
</tr>
<tr>
<td>Sweeney et al.[25]</td>
<td>32 vs 40</td>
<td>34.4 vs 34.6</td>
<td>45.1 vs 44.3</td>
<td>f</td>
</tr>
<tr>
<td>van Aggel-Leijssen et al.[12]</td>
<td>39 vs 39</td>
<td>32.0 vs 32.6</td>
<td>34.6 vs 33.5</td>
<td>m</td>
</tr>
<tr>
<td>Wadden et al.[21]</td>
<td>41 vs 43</td>
<td>36.4 vs 35.3</td>
<td>46.7 vs 46.8</td>
<td>f</td>
</tr>
<tr>
<td>Weinstock et al.[32]</td>
<td>43</td>
<td>35.2 vs 36.4</td>
<td>NA</td>
<td>f</td>
</tr>
<tr>
<td>Wirth et al.[24]</td>
<td>43 vs 44</td>
<td>36 vs 34</td>
<td>29.1 vs 26.8</td>
<td>m and f</td>
</tr>
</tbody>
</table>

**BMI** = body mass index; **f** = female; **m** = male; **NA** = data not available; – indicates no effect of adding exercise training to caloric restriction; + indicates greater fat-mass loss by adding exercise training to caloric restriction.
observed during dietary restriction. Although the authors reported comparable bodyweight losses following dietary restriction or combined dietary restriction and exercise training, the programme including the endurance training regimen resulted in a less significant decline in fat-free mass. As such, exercise intervention seems to be effective as a means to reduce or even prevent the decline in fat-free mass that is generally observed during energy intake restriction.

Although Bond Brill et al.\(^\text{40}\) also reported no differences in fat-mass loss between dietary restriction or a combined dietary restriction/endurance training programme, a greater decline in sagittal and waist diameter was observed in the combined dietary restriction/endurance training programme. These findings imply a preferential loss of central adiposity following a combined energy intake restriction and exercise training programme. This would represent a major health benefit as there is a strong relationship between visceral obesity and insulin resistance, and cardiovascular risk.\(^{41,42}\)

1.2 Site Specific Fat-Mass Loss

Fat-mass loss as a result of dietary intake restriction and endurance exercise training seems to occur in certain regions of the body. Ross et al.\(^\text{43}\) applied magnetic resonance imaging to show a greater relative reduction in the visceral fat depots, when compared with the gluteal/femoral fat depots, following a combined diet-exercise intervention in males. The inclusion of aerobic exercise training, in addition to dietary restriction, seems to facilitate this region-dependent effect.\(^{44,45}\) This indicates that mainly visceral fat depots are under the influence of exercise training and dietary restriction, while the effect is less obvious for the gluteal/femoral fat depots.\(^{12}\) This region-dependent effect might be caused by differences in catecholamine-induced lipolysis and the sensitivity to the anti-lipolytic properties of circulating insulin levels.\(^{46}\) In line with these results, it was shown that abdominal visceral adipocytes are more sensitive to adrenergic stimulation and less sensitive to the anti-lipolytic effect of insulin, when compared with femoral adipocytes.\(^{47}\) This could be caused as a result of an increased $\beta_1$- and $\beta_2$-adrenoceptor density and sensitivity, and reduced $\alpha_2$-adrenoreceptor affinity and number in the abdominal and visceral adipose tissue.\(^{47}\)

1.3 Predictive Factors for Fat-Mass Loss

Dengel et al.\(^\text{10}\) and Wadden et al.\(^\text{31}\) observed a correlation between total baseline bodyweight/fat mass with the subsequent reduction in bodyweight/fat mass following intervention programmes aimed to reduce bodyweight. Subjects with the highest baseline fat mass experienced the greatest absolute fat mass reduction. Furthermore, gender was shown to be a major factor in determining the extent of fat-mass loss. Ballor and Keesey\(^\text{48}\) observed in their meta-analysis that men show a larger bodyweight loss as a result of dietary restriction and exercise training, when compared with women. In contrast, Andersson et al.\(^\text{49}\) showed that the bodyweight and fat-mass loss was comparable between obese men and women as a result of a 3-month combined intervention programme. However, when looking at the data in more detail, it seems that in the Andersson et al.\(^\text{49}\) study, baseline fat mass was greater in the female participants. After correction for differences in baseline fat mass, the men had actually lost a higher amount of fat. The authors explained the discrepancy in fat-mass loss by an increased energy intake in the female subjects, while the men showed no compensation in energy intake for the greater energy expenditure.\(^{49}\)

It seems that obesity is an emerging problem with increasing age and that this could be partially caused by factors such as a lower basal metabolic rate, reduced daily physical activity, endocrine changes and/or the progressive development of insulin resistance.\(^{50,51}\) Although a combination of caloric intake restriction and exercise intervention can effectively reduce fat mass in the elderly,\(^\text{10}\) a direct comparison of fat-mass loss following lifestyle intervention programmes in young and elderly obese subjects is presently unavailable.

Although the prevalence of obesity is higher in African American women compared with Caucasian women in the US,\(^\text{52}\) the response to dietary restric-
tion and exercise intervention on fat-mass loss, as assessed by air displacement plethysmography, has been shown to be similar between the two populations. These results suggest that ethnic differences do not form a major factor in determining programme outcome.

2. Endurance Training and Energy Balance

The only way to prevent obesity is to restore the balance between caloric intake and energy expenditure. Theoretically, the implementation of additional exercise training during caloric restriction should induce an increased negative energy balance and further augment fat-mass loss.

However, most studies indicate that the implementation of endurance training during dietary restriction does not further reduce weight loss or fat-mass loss in obese subjects. This seems to be atypical from an energy balance point of view. However, this can be explained by the observation that after the implementation of exercise training in to the daily routine, people tend to compensate for the increased energy expenditure by increasing energy intake and/or by reducing energy expenditure throughout their daily routine, as assessed by the doubly labelled water method. In this section, we focus on these compensatory mechanisms to explain the rather marginal benefits of endurance training on fat-mass loss during dietary restriction in obese subjects.

2.1 Energy Balance

Bodyweight reduction as result of exercise training and energy intake restriction is attributed to the change in energy balance, in which energy expenditure is increased through physical exercise and energy intake is either maintained or reduced. The three most important factors in this energy balance are: (i) food intake; (ii) energy expenditure through physical activity; and (iii) energy expenditure through basal metabolic rate.

It has often been suggested that a high dietary fat intake is the main cause for an increase in bodyweight over the years, resulting in overt obesity. However, Hill and Melanson suggested that there are only minor differences in total energy and/or fat intake between lean and obese subjects. In addition, by measuring total energy expenditure with the doubly labelled water method, Schoeller reported that obese individuals maintain their obese state with an energy intake lower than those of lean individuals. According to these data, the obesity epidemic is more likely to be a result of lifestyle changes than merely changes in dietary intake. In accordance, others have reported that the substantial progressive decline in the level of physical activity over the last few decades is largely responsible for the increased prevalence in obesity in our Western society. These results were obtained through high-quality daily physical activity assessment procedures, such as a respiratory chamber combined with the use of body accelerometers and the doubly labelled water method.

During dietary restriction interventions, energy intake is profoundly reduced. People have been reluctant to superimpose exercise training in addition to the caloric restriction regimen as this would likely affect hunger/satiety and could consequently reduce compliance to the dietary restriction. However, data indicate that long-term exercise training does not increase hunger or daily food intake. Blundell et al. showed that, after correction for the increase in energy expenditure, food consumption following combined exercise and dietary restriction was similar or even reduced when compared with energy restriction only. Only 30% of the consumed energy during exercise training was compensated through elevated food intake. So, exercise training actually seems to stimulate the maintenance of a more negative energy balance.

2.2 Energy Expenditure and Physical Exercise

Physical activity levels have declined dramatically over the last few decades. The reduction in daily physical activity in our modern civilisation is associated with a progressive, long-term increase in bodyweight. Following the implementation of dietary intake restriction, energy expenditure is further decreased by a compensatory decline in daily energy expenditure.
physical activity.\cite{59} The implementation of an endurance exercise programme seems to be effective in preventing this decline in daily energy expenditure during dietary restriction. Moreover, Racette et al.\cite{38} observed that 12 weeks of dietary restriction resulted in decreased daily physical activity in obese women. Interestingly, when these subjects participated in an endurance training regimen (3 sessions per week, 45 minutes per session), their average daily physical activity outside the training centre also significantly increased. Discrepent findings were reported by Kempen et al.\cite{37} Following energy intake restriction, they also reported a reduction in daily energy expenditure. However, the implementation of an endurance training programmes did not increase total daily energy expenditure, as subjects compensated for their reduced energy intake by reducing daily physical activity outside the training centre. There is no apparent explanation for the contradictory findings, as the subject populations and intervention types between studies were nearly identical. Nonetheless, an important difference in daily physical assessment methodology was found between these studies. Kempen et al.\cite{37} assessed daily physical activity level by dividing average daily metabolic rate by sleeping metabolic rate, and by subtracting sleeping metabolic from average daily metabolic rate. Racette et al.\cite{38} measured daily physical activity level with identical calculations, although they added results from 7-day physical activity questionnaires and continuous heart-rate monitoring. As both studies assessed physical activity levels with excellent methodology, it remains speculative whether exercise training affects daily physical activity. Therefore, it seems to be impossible to predict the effect of additional exercise training on daily physical activity and, as such, on overall energy balance. As a result of these discrepant findings in the literature, more research is warranted to elucidate how endurance training affects daily physical activity and how to design exercise interventions that are most effective in modulating daily energy balance.

2.3 Basal Metabolic Rate

Basal metabolic rate accounts for approximately two-thirds of the total resting energy expenditure. Ravussin et al.\cite{60} showed that basal metabolic rate represents a good predictor for long-term weight gain. During a 2-year follow-up, the risk of gaining >7.5kg of bodyweight increased 4-fold for those patients with a low adjusted 24 hour resting energy expenditure. Following dietary restriction, basal metabolic rate tends to decrease by 10–20%.\cite{18,21,36,37,61,62} The implementation of endurance exercise training does not seem to prevent this decline in basal metabolic rate, according to studies using open circuit spirometry.\cite{18,21,36,37,61,62} Whatley et al.\cite{21} reported no significant effects on the decline in basal metabolic rate following the addition of both moderate (200 minutes per week) or longer (400 minutes per week) periods of endurance exercise to a dietary restriction intervention. This seems to be in accordance with the observation that endurance exercise training does not augment fat-mass loss during energy intake restriction.

2.4 Fat Oxidation

Generally, obesity is secondary to the long-term presence of a mismatch between energy intake and energy expenditure. However, there is also evidence to suggest that metabolic disturbances are responsible for weight gain in obese patients. A disturbed fat oxidative capacity could be an important factor in the aetiology of obesity. Zurlo et al.\cite{63} reported that resting respiratory quotient (RQ) forms a good predictor of bodyweight gain. In this study, subjects with a high baseline 24-hour RQ (90th percentile) had a 2.5-fold higher risk of gaining >5kg bodyweight during follow-up than subjects with a low resting RQ (10th percentile). Hainer et al.\cite{64} found similar effects on resting RQ on long-term bodyweight control in obese patients after completing a very low energy intake diet. These studies suggest that basal fat oxidation rate represents an important factor in bodyweight management.

Unfortunately, dietary restriction often leads to an additional decline of the basal fat oxidation rate.\cite{12} This is an important negative effect as the
maintenance or reduction of bodyweight gets more difficult as the dietary intervention progresses. The addition of exercise training to dietary restriction becomes interesting since one might assume that increased physical activity prevents the decline of basal fat oxidation. Whether exercise training has a stimulating effect on basal fat oxidation rate and fat oxidation capacity during exercise conditions in obese patients remains a matter of debate.

Some authors have reported no effect of endurance exercise training on basal fat oxidation rate, whereas others have reported a stabilisation or even an increased basal fat oxidation rate. Since the applied assessment procedure for fat oxidation analysis (indirect calorimetry, some in combination with stable isotope tracer methodology) is not substantially different between studies, this is not likely to be responsible for the apparent contradictory findings. Nonetheless, analysis of the baseline lipid oxidation capacity-affecting factors (e.g. intramyocellular triacylglycerol content, mitochondrial density, fatty acid binding protein and β-oxidation enzyme activity) should be incorporated in these studies. It may be the case that these baseline factors vary considerably between obese individuals, consequently affecting changes in lipid oxidation capacity by exercise training. Besides these suggestions, the discrepant findings in the literature may be related to differences in training modalities in the various exercise intervention programmes. In accordance, Goodpaster et al. reported a significant correlation between the stabilisation of basal fat oxidation rate and energy expenditure of the exercise training sessions. The higher the energy expenditure during training, the greater the chance of stabilisation of the resting fat oxidation rate during caloric restriction. In conclusion, it still remains to be established whether there are any positive effects of additional endurance training during caloric restriction on basal resting fat oxidation rate in obese subjects.

The effects of exercise training, as an addition to caloric restriction, on the fat oxidation capacity during exercise are also controversial. Kanaley et al. found no influence of 16 weeks of additional endurance training on the fat oxidation capacity during exercise in obese women during caloric restriction. However, important influences of training intensity and body fat distribution were reported in other studies and might explain this negative result. Van Aggel-Leijssen et al. reported an increase in fat oxidation rates during exercise following a low-intensity endurance exercise training programme, whereas no effects were reported following a high-intensity endurance training. A different study also indicated that besides training intensity, body fat distribution tends to modulate the training response on fat oxidation capacity during exercise. Van Aggel-Leijssen et al. clearly showed that only female patients with abdominal adiposity showed an increase in fat oxidation capacity during moderate-intensity exercise, following the low-intensity endurance training. Female patients with predominantly gluteal-femoral adiposity showed no changes in fat oxidation capacity during exercise. These results suggest that visceral fat depots are more susceptible to exercise training when compared with the gluteal-femoral fat depots. Therefore, future studies on this topic should take into account body-fat distribution and training intensity in order to explain the effects of additional endurance training during caloric restriction on fat oxidation capacity during exercise in obese subjects.

Circulating plasma-free fatty acids could play an important role in the presence or absence of possible effects of exercise and/or dietary intervention on fat oxidation rates. However, a stable isotope study indicated that the reported increase in fat oxidation rate during exercise, as a result of endurance training, is entirely attributed to an increase in the use of fat sources other than plasma-free fatty acids. These other fat sources include lipoprotein and/or intramuscular-derived triacylglycerol. The increase in the use of the intramuscular triacylglycerol pool following endurance training is likely to be associated with alterations in cellular metabolism.
et al muscle insulin sensitivity\cite{66,67,73} and $\beta$-adrenergic sensitivity.\cite{12,74,75}

3. Influences of Training Modalities on Fat-Mass Loss

The addition of an exercise regimen within a dietary restriction programme does not seem to induce a substantially greater fat-mass loss than dietary restriction alone. This neutral effect can be attributed to a decreased physical activity level outside the training centre and the lack of a stimulating or stabilising effect on the basal metabolic rate and resting fat oxidation capacity. However, the efficacy of an exercise intervention programme to stimulate fat-mass reduction might be determined by many of its components. In this section, the role of different training modalities on stimulating fat-mass reduction are reviewed, including training intensity, amount of exercise, type of exercise and inclusion of resistance exercise (see table II). From table II, it should be noted that only a few studies investigated male obese subjects.

3.1 Exercise Intensity

In clinical practice, obese patients are generally advised to participate in a low-intensity exercise programme. Ballor et al.\cite{15} compared the following two subgroups of obese women during energy intake restriction: (i) a high intensity training group (exercising for 25 minutes at 80–90% peak oxygen uptake [VO$_{2\text{peak}}$] per session); and (ii) a low intensity training group (exercising for 50 minutes at 40–50% VO$_{2\text{peak}}$ per session). After 8 weeks (three sessions per week) of exercise training, no differences in fat mass or body composition were observed between the two groups (as assessed by hydrostatic weighing). Leutholtz et al.\cite{76} investigated the influence of endurance training at 40% and 60% of heart rate reserve (three sessions per week, over a 3-month period), in combination with a dietary restriction intervention. No differences in fat mass or bodyweight loss were observed between the groups. However, it should be noted that bio-electrical impedance analysis was applied to assess fat mass in this study, which has been shown to represent a method with questionable precision.\cite{79} Van Aggel-Leijssen et al.\cite{13} also showed no influence of training intensity (40% vs 70% maximal oxygen uptake [VO$_{2\text{max}}$]) on fat-mass loss or body composition following 12 weeks of endurance training in obese men (as assessed by hydrostatic weighing). The absence of marked differences in bodyweight and/or fat mass between high- and low-intensity training might simply be attributed to the fact that the studied obese subjects are generally sedentary with a very low exercise capacity. As a result, absolute differences in energy expenditure between a workload set at their individual 40–50% VO$_{2\text{max}}$ and a 70–80% VO$_{2\text{max}}$ might simply be negligible on the whole-body fat-mass balance.

The available data suggest that training intensity does not represent a major factor in determining fat-mass loss during dietary intake restriction in obese subjects. However, compliance to an exercise regimen has been reported to be associated with the impact of the training workload.\cite{80} Because compliance to a high-intensity training programme is likely to be lower than to a low-intensity training programme, this could explain the absence of a greater reduction in fat-mass loss in high-intensity training programmes. Wadden et al.\cite{31} reported treatment attendance at the training centre to correlate with the resultant weight loss during a combined dietary restriction and exercise training programme in obese subjects. As compliance to an exercise programme is a main factor determining the efficacy and long-term weight maintenance, low-intensity exercise programmes seem to be preferred when designing combined dietary and exercise intervention programmes to reduce bodyweight/fat mass in obese patients.

3.2 Amount of Exercise

In a study of Bond Brill et al.,\cite{40} the dose-dependent effect of walking on body composition was analysed during a dietary restriction programme. One group of obese women were instructed to walk for 30 minutes, 5 days a week, whereas the other group walked for 60 minutes, 5 days a week. After 12 weeks of training, no differences in
Table II. Influences of training modalities on fat-mass loss during caloric restriction in obese subjects

<table>
<thead>
<tr>
<th>Author (reference)</th>
<th>Subject characteristics (two groups compared in each study)</th>
<th>Analysed training modality</th>
<th>Effects of training modality on fat-mass loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean age</td>
<td>mean BMI (kg/m²)</td>
<td>mean % fat</td>
<td>sex</td>
</tr>
<tr>
<td>Ballor et al. [15]</td>
<td>NA</td>
<td>NA</td>
<td>36.1 vs 37.5</td>
</tr>
<tr>
<td>Leutholtz et al. [76]</td>
<td>43 vs 40</td>
<td>NA</td>
<td>44.4</td>
</tr>
<tr>
<td>van Aggel-Leijssen et al. [13]</td>
<td>43 vs 40</td>
<td>31.6 vs 32.2</td>
<td>31.9 vs 31.3</td>
</tr>
<tr>
<td>Bond Brill et al. [40]</td>
<td>39 vs 40</td>
<td>35.3 vs 33.8</td>
<td>41.6 vs 41.2</td>
</tr>
<tr>
<td>Jeffery et al. [77]</td>
<td>42</td>
<td>31.7</td>
<td>NA</td>
</tr>
<tr>
<td>Whatley et al. [71]</td>
<td>39 vs 36</td>
<td>36.0 vs 35.4</td>
<td>45.8 vs 43.5</td>
</tr>
<tr>
<td>Gwinup [78]</td>
<td>31 vs 28 vs 32</td>
<td>NA</td>
<td>30–40</td>
</tr>
<tr>
<td>Donnelly et al. [14]</td>
<td>NA</td>
<td>38.2 vs 38.2</td>
<td>47.0 vs 45.5</td>
</tr>
<tr>
<td>Marks et al. [34]</td>
<td>38 vs 39</td>
<td>30.1 vs 30.4</td>
<td>41.5 vs 40.9</td>
</tr>
<tr>
<td>Pronk et al. [19]</td>
<td>42 vs 36</td>
<td>NA</td>
<td>47.4 vs 45.3</td>
</tr>
<tr>
<td>Ross et al. [42]</td>
<td>47 vs 39</td>
<td>31.6 vs 33.5</td>
<td>NA</td>
</tr>
<tr>
<td>Wadden et al. [31]</td>
<td>41 vs 40</td>
<td>36.4 vs 36.5</td>
<td>46.7 vs 45.0</td>
</tr>
<tr>
<td>Weinstock et al. [32]</td>
<td>43</td>
<td>35.2 vs 36.2</td>
<td>NA</td>
</tr>
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<td>Ashutosh et al. [14]</td>
<td>41 vs 45</td>
<td>NA</td>
<td>f</td>
</tr>
<tr>
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<td>NA</td>
<td>37.5 vs 38.3</td>
<td>46.6 vs 46.5</td>
</tr>
<tr>
<td>Donnelly et al. [32]</td>
<td>NA</td>
<td>NA</td>
<td>46.7 vs 46.2</td>
</tr>
<tr>
<td>Marks et al. [34]</td>
<td>39 vs 40</td>
<td>28.7 vs 31.3</td>
<td>38.3 vs 43.3</td>
</tr>
<tr>
<td>Sweeney et al. [44]</td>
<td>32 vs 29</td>
<td>34.3 vs 36.7</td>
<td>45.1 vs 44.9</td>
</tr>
<tr>
<td>Wadden et al. [31]</td>
<td>41 vs 43</td>
<td>37.3 vs 35.3</td>
<td>47.3 vs 44.2</td>
</tr>
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BMI = body mass index; ex = exercises; f = female; m = male; NA = data not available.
fat-mass loss were observed between the groups, as determined by the hydrodensitometry method.\(^\text{[40]}\) Whatley et al.\(^\text{[21]}\) compared the effects of two exercise intervention programmes in obese females. One group exercised for 400 minutes per week (five sessions per week), whereas the other group exercised for just 210 minutes per week (three sessions per week) for a period of 12 weeks, during which energy intake was restricted. In this study, the training group with high levels of exercise lost considerably more fat mass through underwater weighing than the low-level training group (16 ± 4kg vs 13 ± 4kg, respectively). Furthermore, a significant correlation between fat-mass loss and total work duration was reported. In accordance, Jeffery et al.\(^\text{[77]}\) reported an important contribution of energy expenditure during exercise to weight loss in obese patients. In their study, one group of obese patients was included into a standard behaviour intervention programme with an energy expenditure goal of 1000 kcal/week, whereas a second group received the same behaviour intervention programme, together with a high physical activity treatment (energy expenditure at 2500 kcal/week). After 12 and 18 months, the reported cumulative weight loss was significantly higher in the highly active versus the standard intervention group. Again, the reported weight loss correlated well with the estimated energy expenditure.

The results of Whatley et al.\(^\text{[21]}\) and Jeffery et al.\(^\text{[77]}\) were in clear contradiction with those of Bond Brill et al.\(^\text{[40]}\) However, in the study by Bond Brill et al.,\(^\text{[40]}\) the training intensity was self-selected and not recorded, while this was standardised in the studies by Whatley et al.\(^\text{[21]}\) and Jeffery et al.\(^\text{[77]}\). Analysis of \(\dot{V}O_2\text{peak}\) in the study by Bond-Brill et al.\(^\text{[40]}\) revealed that the subjects improved their peak exercise capacity to a greater extent as a result of short training sessions (11.7% increase in \(\dot{V}O_2\text{peak}\)), compared with long training sessions (6.6% increase in \(\dot{V}O_2\text{peak}\)). Therefore, it might be suggested that during the short exercise bouts the subjects trained at a higher self-chosen intensity compared with the long exercise bouts. Consequently, the differences in caloric expenditure as a result of exercise training between groups might have disappeared and no differences in fat-mass loss between the groups could be found. Therefore, Whatley et al.\(^\text{[21]}\) and Jeffery et al.\(^\text{[77]}\) provided more reliable results for interpreting the effects of the amount of exercise training on fat-mass loss.

In conclusion, increasing the amount of training seems to represent an effective means to augment the net decline in fat mass/bodyweight during a combined dietary and exercise intervention programme.

### 3.3 Type of Endurance Exercise

The type of exercise that is most effective in reducing body fat in obese subjects remains unclear. Gwinup\(^\text{[78]}\) investigated the effects of a walking, cycling or swimming regimen on bodyweight in 29 obese women, in the absence of any dietary restriction. All women progressively increased physical activity up to 60 minutes per day. After 6 months of exercise training, only the cycling and walking groups showed a significant decline in bodyweight, whereas no changes were observed in the swimming group. However, it should be noted that training intensity and/or energy expenditure were not standardised in this study. Furthermore, as changes in body composition were not assessed in this study, no information was provided on the changes in fat-free mass and fat mass in each of the intervention groups. More research is warranted to confirm these results. When performed at the same relative workload, energy expenditure is considerably higher during walking than with arm cycling or cycling.\(^\text{[81]}\) In addition, during walking the relative contribution of fat oxidation to total energy expenditure is higher when compared with cycling at an identical relative workload.\(^\text{[82]}\) Considering the relationship between caloric expenditure during training and fat-mass loss, walking (and/or running) exercise seems to be the preferred type of exercise in obese patients.

### 3.4 Resistance Exercise

The implementation of resistance exercise training within a dietary intake restriction programme\(^\text{[16,19,30-32,43]}\) or a combined dietary restriction...
and endurance training programme\textsuperscript{[14,16,25,30,31,33]} has been intensively studied. Even though energy expenditure was increased as a consequence of resistance training, it was not sufficient to augment fat-mass loss. The change in bodyweight, as a result of endurance exercise training and/or dietary restriction, could not be modulated through resistance training.

Despite the absence of any effects of resistance exercise on fat-mass loss, positive effects have been reported regarding muscle/fat-free mass. The addition of resistance training to dietary restriction and/or endurance training prevents the loss of fat-free mass, secondary to dietary restriction.\textsuperscript{[83]} Sweeney et al.\textsuperscript{[25]} reported, by applying hydrostatic weighing, a smaller decline in fat-free mass following a combined endurance and resistance training programme in obese patients under dietary restriction after 3 months of intervention, when compared with endurance training alone. In addition, the same methodology was applied by Geliebter et al.\textsuperscript{[18]} showing that the inclusion of resistance exercise training in a dietary intervention programme (without endurance training) prevented the loss of fat-free mass in obese subjects.

As such, it seems that resistance training should form an integrative part of any exercise intervention to improve muscle mass and function.\textsuperscript{[84]} This decreased functional capacity is especially relevant for the older obese patient in which age-related loss of muscle mass (sarcopenia) causes a progressive decline in functional capacity. This can lead to a further reduction in daily physical activity, accelerating fat-mass gain and the development of chronic metabolic diseases.

Since endurance exercise performance can be improved with the implementation of resistance training,\textsuperscript{[85]} this could assist in the overall process of weight reduction through exercise training and in the prevention of other important negative effects of caloric restriction. Similar to the observations regarding fat-free mass, resistance training prevents the decline in resting metabolic rate, which is generally observed during dietary restriction.\textsuperscript{[86]}

In conclusion, the addition of resistance training to endurance training and dietary restriction programmes does not modulate fat-mass loss, but prevents the decline in fat-free mass and resting metabolic rate. As such, resistance training can represent an effective means to improve body composition and maintain the reduced fat mass.

4. Future Directions

The most striking finding in this review is the neutral effect of additional exercise training on fat-mass loss during caloric restriction. There might be an indication that alterations in daily physical activity and food intake patterns, as a result of this exercise training programme, suppresses the effects on fat-mass loss, although no conclusive evidence could be provided. Therefore, it remains to be examined how exercise training affects food intake and daily physical activity outside the training centre in obese subjects during caloric restriction. Are there compensatory behavioural actions in these patients and how can we deal with them?

In addition, most studies focus on fat-mass change, while many of the obesity-related health complications, such as insulin resistance and cardiovascular disease, are affected by exercise training, even in the absence of measurable changes in body-fat mass. For example, the fat mass/fat-free mass ratio, daily physical functioning, quality of life and feelings of well-being have been reported to improve with exercise training in obese subjects in the absence of significant changes in fat mass. Therefore, exercise interventions studies should not limit their focus on changes in fat mass, but should provide an insight into the many other health benefits of lifestyle intervention in the prevention and treatment of chronic metabolic diseases.

Furthermore, it remains to be elucidated how exercise training affects resting and fat oxidation capacity during exercise. As this capacity is a strong predictor for long-term bodyweight control and it could potentially be affected by exercise training, efforts in this area might provide great insights for reversing obesity through exercise training. For example, it might be of interest to assess the effects of

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exercise training modalities (e.g. intensity, bout duration, frequency, inclusion of strength exercises) on fat oxidation capacity at rest and during exercise in obese individuals.

There is considerable evidence to support the inclusion of resistance exercise and caloric restriction to exercise training as a means to further improve body-fat mass loss and body composition. However, only a few studies have investigated the effects of the type, intensity, duration, frequency and mode of training in subjects at risk of developing chronic metabolic disease (e.g. cardiovascular disease, type 2 diabetes). Therefore, it is necessary to elucidate the effects of these training modalities both on fat-mass loss during caloric restriction, as well as on the prevention of cardiovascular/metabolic disease in obese individuals.

Finally, as most investigations have included obese women, further studies should be performed to assess potential gender differences in the response to exercise training. This could result in exercise intervention programmes being designed specifically for each gender in order to optimise health benefits.

5. Conclusions

Dietary restriction combined with endurance exercise training represents an effective strategy to promote weight loss and reduce fat mass in obese patients. Exercise interventions without dietary restriction are less efficient. Generally, addition of exercise interventions within a dietary restriction programme does not induce a greater fat-mass loss than dietary restriction alone. This is attributed to a compensatory reduction in daily physical activity following the implementation of exercise training. As obese patients are often focused on reducing bodyweight, it is of great importance to point towards the other health benefits of additional exercise training, which include the following: prevention of a decrease in fat-free mass; a higher dietary compliance and better maintenance of bodyweight at a long-term; and a relative greater loss of visceral fat mass. The reduction in fat mass in a combined dietary and exercise intervention programme is primarily established at visceral fat depots and to a lesser extent at the gluteal/femoral fat depots, and is associated with an improved insulin sensitivity and lipid profile. Obese male patients with the highest fat mass are most susceptible to losing the largest amount of fat mass.

Various training modalities of the exercise intervention programme, when combined with energy intake restriction, seem to effect fat-mass loss. There seems to be no direct influence of training intensity on fat-mass loss. So, a low-intensity training regimen is preferred, because of greater compliance. As a greater amount of exercise training induces a greater fat-mass loss, the relationship between energy expenditure during exercise training and fat-mass loss has been established. There might be an influence of the type of exercise on fat-mass loss; walking and cycling have been shown to reduce bodyweight, whereas swimming does not. The inclusion of resistance training in addition to a dietary restriction intervention does not influence fat-mass loss, but could augment fat-free mass and, as such, prevent a decrease in basal metabolic rate during energy intake restriction.

For obese patients, the following intervention programme can be proposed: combined caloric restriction and endurance training at three to five training sessions per week. The training intensity should be moderate (55–65% $\dot{V}O_2$max), while the training session duration should be long (>1 hour). Walking or cycling exercises are preferred, in combination with strength training exercises.

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References


51. Elia M. Obesity in the elderly. Obes Res 2001 Nov; 9 Suppl. 4: S244-8
59. Westerterp KH. Obesity and physical activity. Int J Obes 1999 Feb; 23 Suppl. 1: S59-64
80. Perri MG, Anton SD, Durning PE, et al. Adherence to exercise prescriptions: effects of prescribing moderate versus higher levels of intensity and frequency. Health Psychol 2002 Sep; 21 (5): 452-8
82. Achten J, Venables MC, Jeukendrup AE. Fat oxidation rates are higher during running compared with cycling over a wide range of intensities. Metabolism 2003 Jun; 52 (6): 747-52

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