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REVIEW ARTICLE

# The Impact of Obesity Surgery on Musculoskeletal Disease

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**Abstract** Obesity is an important modifiable risk factor for musculoskeletal disease. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-compliant systematic review of bariatric surgery on musculoskeletal disease symptoms was performed. One thousand nineteen papers were identified, of which 43 were eligible for data synthesis. There were 79 results across 24 studies pertaining to physical capacity, of which 53 (67 %) demonstrated statistically significant post-operative improvement. There were 75 results across 33 studies pertaining to musculoskeletal pain, of which 42 (56 %) demonstrated a statistically significant post-operative improvement. There were 13 results across 6 studies pertaining to arthritis, of which 5 (38 %) demonstrated a statistically significant post-operative improvement. Bariatric surgery significantly improved musculoskeletal disease symptoms in 39 of the 43 studies. These changes were evident in a follow-up of 1 month to 10 years.

**Keywords** Bariatric · Metabolic surgery · Weight loss/reduc* · Musculoskeletal · *arthritis · Health econ* · Pain · Physical capacity

## Introduction

Obesity, defined as a body mass index (BMI) of greater than 30 kg/m$^2$, has been recognised as a global epidemic for many years [1], with an estimated 315 million adults affected worldwide [2]. This poses a huge health and economic burden, as it is widely established that morbid obesity is a significant risk factor in the development of many chronic diseases. These include coronary artery disease, hypertension, dyslipidaemia and diabetes mellitus [3–5]. Although the effects of obesity (and weight reduction) on these conditions have received the focus of attention in terms of obesity health policy, there are additional significant impacts on psychosocial and musculoskeletal health in the form of arthropathy, musculoskeletal pain, loss of mobility and loss of physical capacity [6–8].

A number of conservative and medical treatments of obesity have previously been recommended, ranging from lifestyle modification to pharmacological therapies, with little success [9–11]. A recent Cochrane review and Health Technology Assessment has demonstrated that surgical management of obesity is clinically more effective than conventional treatment [12, 13].

Obesity is associated with musculoskeletal pain and osteoarthritis, with the lower back and knees most commonly affected. Raised BMI leads to abnormally increased joint loads which in turn alters the structure and composition of articular cartilage [14]. Altered articular cartilage is less able to absorb excess loading forces, which can then lead to deformation of affected joints [15]. Additionally, in obese subjects, skeletal muscle is laden with intramuscular fat which releases systemic and local pro-inflammatory mediators, such as IL-6 and TNF-α. This creates a worsening cycle of local inflammation that, in combination with mechanical factors, leads to a variety of musculoskeletal impairments [16]. These include various pathological phenotypes, such as osteoarthritis and reduced muscle mass, as well as their occupational and lifestyle consequences, such as reduced physical capacity, slower walking speed and musculoskeletal pain [17].

The direct costs of treating obesity and the indirect costs associated with loss of productivity are huge [18]. Recent publications have estimated the direct cost of obesity and related illnesses in the UK at £4.3 billion–£5.1 billion (Euro €5.2 billion–€6.1 billion, US $7.2 billion–$8.5 billion) [19,

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20]. The National Institute for Health and Clinical Excellence (NICE) has recently estimated the indirect costs to be UK £2 billion (Euro €2.4 billion, US $3.3 billion) [21]. Similar scales of expenditure are seen elsewhere in the developed world, with an annual total direct and indirect cost of US $139 billion (UK £84 billion, Euro €101 billion) [22] and CDN $4.3 billion (UK £2.3 billion, Euro €2.8 billion, US $3.9 billion) in the USA and Canada, respectively [23].

As obesity is the single most important modifiable risk factor in the progression of osteoarthritis and other musculoskeletal disorders, the impact of bariatric surgery on physical function, and therefore on Health Care Quality of Life (HCQoL) and productivity, may be significant. Bariatric surgery may represent an area of health care reform that can lead to both significant improvements in clinical outcomes and broader economic cost-effectiveness.

In this paper, we aim to provide a systematic review of the impact of bariatric surgery on physical function, musculoskeletal pain and arthritis.

## Methodology

This systematic review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement to improve transparency and completion of our reporting [24]. A study protocol documenting keywords, inclusion and exclusion criteria was produced in advance and agreed by consensus.

### Literature Search

A systematic review of the literature was performed using multiple electronic search engines including PubMed, MEDLINE, Ovid and Embase. The search terms, agreed by consensus, are listed as follows:

> (bariatric OR (weight surgery)) AND mobility
> (bariatric OR (weight surgery)) AND (((QoL OR (Quality of Life)) AND pain)
> (bariatric OR (weight surgery)) AND (musculoskeletal)
> (bariatric OR (weight surgery)) AND arthritis

The search was repeated with the word "weight" replaced with "obesity", and the results of the two searches were combined.

The above terms were generated with the aid of consultant bariatric surgeons with significant experience in surgical academia. The "related" function was used in Pubmed to identify additional papers. References of the articles identified were also searched for by title and, where necessary, abstract review. Relevant systematic reviews' reference lists were examined, and any relevant papers encountered that were not retrieved in the original database search were also included. Figure 1 provides an overview of search outcomes according to the PRISMA protocol.

### Eligibility Criteria and Data Extraction

All peer-reviewed published data that investigated the impact of bariatric surgery on post-operative musculoskeletal pain, arthritis and physical function were considered. The search was restricted to studies published in English, but there were no restrictions on study age, type of study or cohort size.

All papers were reviewed by an author with experience in data extraction and publication of systematic reviews (UE) and were cross checked by a second author (SP). Relevant articles were title and abstract reviewed and, where necessary, also reviewed in full text. Any uncertainty as to inclusion was agreed by consensus.

### Inclusion and Exclusion Criteria

To be included in the data analysis, a study had to report a method of determining the impact of bariatric surgery on any of the following outcomes: physical function (including mobility), musculoskeletal pain, arthritis and at any point post-operatively. Studies solely investigating biochemical changes or any other non-musculoskeletal parameter were not included.

In view of our inclusion of all levels of evidence, all papers were scored for quality of evidence in accordance with the

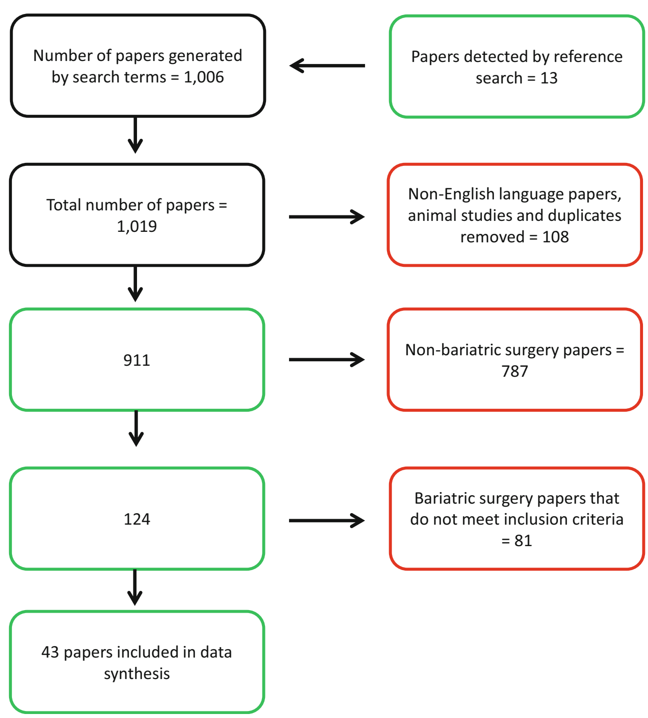


**Fig. 1** Flowchart of search outcomes according to the PRISMA protocol

original (1989) US Preventive Services Task Force Recommendations instead of the 2011 recommendations. This is because the 1989 guidelines were more objective and provided more subsets of levels of evidence [25].

### Data Analysis

Data was extracted from the included studies and tabulated using Microsoft Excel. Due to the heterogeneity of the methods and results of the papers identified and used in this review, it was not possible to perform a quantitative meta-analysis.

All cost figures are provided in the currency originally cited. Equivalent values in other currencies are included in parentheses, calculated at the exchange rate at the time of writing.

## Results

### Literature Search

The initial search identified 1,019 citations. After removing duplicates, papers not written in English and papers not related to bariatric surgery, 124 papers remained. Of these, 81 did not meet the inclusion criteria detailed above. The final number of papers included in this systematic review was 43 (Fig. 1) [26–68].

### Quality of Evidence

All 43 papers were assigned a quality of evidence score in accordance with the original US Preventive Services Task Force Ratings [25]. There were 37 prospective studies and 6 retrospective studies. Of the 37 prospective studies, 3 were randomised controlled trials (level I evidence), 2 were non-randomised controlled trials (II—1), and 10 were prospective cross-sectional trials, including 2 studies that also contained a prospective longitudinal study within it (level II—2 evidence). The remaining 22 studies were prospective longitudinal studies (level II—2 evidence). The largest sample population of the prospective studies was 1,916 and the smallest was 14. The six retrospective studies had sample populations ranging from 15 to 5,502 (level II—3 evidence).

Of the 43 studies in this review, 15 did not use a validated tool to assess the inclusion outcomes. The remaining 28 studies used a variety of 24 different validated outcome tools, with the SF-36 questionnaire the most frequently utilised (15 times) (Table 1).

### Outcome Measures

No single study investigated all three outcomes. Of the 43 studies, 22 reported on two outcomes. This also included a paper that did not clearly specify outcomes, but the description in the text was deemed by consensus to meet both mobility and musculoskeletal (MSK) pain [56]. The remaining 21 reported on a single outcome. Musculoskeletal pain was investigated in 33 studies, mobility in 24 studies and arthritis in 6 studies (Table 1).

### Mobility

Table 2 refers to all studies that investigated the impact of bariatric surgery on post-operative mobility. Follow-up ranged from 1 month to 10 years. Each component of the relevant outcome questionnaire across the 24 mobility studies was individually deconstructed to provide 79 individual results, listed in chronological order. The authors of four papers did not supply information on statistical significance for 14 of the 79 individual results [33, 40, 44, 56]. Of these 14 results, 1 showed no difference in physical function between open and laparoscopic bariatric surgery groups [40], and the remaining 13 results all showed a tendency to improved mobility or physical function post-operatively [33, 44, 56].

Of the remaining 65 individual results for which the authors confirmed statistical significance, 4 demonstrated a worsening in physical function between 1 and 5 years post-operatively (derived from one study) [32]. Of the remaining 61 results, 3 showed no difference in comparison to population norms [28, 40], 2 showed no difference in physical function scores [26], 1 showed no significant difference between patients in different surgery groups [29], 1 showed a worsening in comparison to population norms [28], and 1 showed a worsening in the surgical group compared to the non-surgical control group [29]. The remaining 53 results all demonstrated significant improvements in physical function.

### Pain

Table 3 refers to all studies that investigated the impact of bariatric surgery on post-operative musculoskeletal pain. Follow-up ranged from 1 month to 10 years. Each component of the relevant outcome questionnaire across the 33 musculoskeletal pain studies was individually deconstructed to provide 75 individual results, listed in chronological order. Of the 75 individual results, 42 pertained to a named anatomical region; most commonly the back followed by the knee.

Of these 75 results, the authors did not supply information on statistical significance for 29 of them [31, 35, 38–40, 44, 47, 49, 54–56, 66, 67]. Of these 29 results, 2 had no difference in pain scores [31, 39], and 1 showed a worsening in pain score between 1 and 3 years post-operatively [39]. The remaining 26 results all demonstrated an improvement in pain.

Of the 46 individual results for which the authors provided information on statistical significance, 1 showed no difference

**Table 1** Overview of all papers, ranked in order of quality of evidence

| Author | Year | Country | Quality of evidence*/study type | *n* | Operation[a] | Validated tool | Outcomes |
|---|---|---|---|---|---|---|---|
| Schouten R | 2011 | Holland | I/RCT | 100 | LAGB, VBG | NHP-I, NHP II, SIP-68 | Mobility, MSK pain |
| Søvik TT | 2011 | Norway, Sweden | I/RCT | 60 | LGB, LDS | SF-36 | Mobility, MSK pain |
| Nguyen NT | 2001 | USA | I/RCT | 155 | LGB, OGB | SF-36 | Mobility, MSK pain |
| Choi J | 2010 | USA | II-1/CT | 66 | LAGB | Not used | Arthritis |
| Melissas J | 2001 | Greece | II-1/CT | 125 | VBG | Not used | MSK pain |
| Zhang N | 2012 | USA | II-2/X-S + Longitudinal | 558 | LSG, LRYGB | Not used | Mobility, MSK pain |
| Vincent HK | 2012 | USA | II-2/X-S | 45 | LAGB, LGB | SF-36, pain VAS score, FAP score, Likert physical activity score | Mobility, MSK pain |
| Strain GW | 2011 | Canada | II-2/X-S | 77 | LSG | SF-36, IWQOL-Lite | Mobility, MSK pain |
| EM | 2007 | Holland | II-2/X-S | 236 | VBG, GB | NHP I, NHP II | Mobility, MSK pain |
| Sampalis JS | 2006 | Canada | II-2/X-S | 1035 | RYGB, RYiGB, VBG, LRYiGB | Not used | Arthritis |
| Sanchez-Santos R | 2006 | Spain | II-2/X-S | 123 | RYGB | EuroQol 5D | Mobility |
| Alsabrook GD | 2006 | USA | II-2/X-S | 77 | ORYGB | Not used | MSK pain |
| Dziurowicz-Kozłowska A | 2005 | Poland | II-2/X-S + Longitudinal | 61 | VBG, RYGB | NHP-I | Mobility |
| Melissas J | 2003 | Greece | II-2/X-S | 50 | VBG | Not used | MSK pain |
| Peltonen M | 2003 | Sweden | II-2/X-S | 1,916 | Gba, VBG, GB | Not used | MSK pain |
| Aftab H | 2013 | Norway | II-2/Longitudinal | 184 | LGB | SF-36 | Mobility, MSK pain |
| Julia C | 2013 | France | II-2/Longitudinal | 71 | RYGB | SF-36 | Mobility, MSK pain |
| Iossi M | 2013 | USA | II-2/Longitudinal | 47 | RYGB | SF-36, TGUG, SMFA | Mobility |
| Grans R | 2012 | Brazil | II-2/Longitudinal | 26 | Not specified | SF-36, HBD + VAS | Mobility, MSK pain |
| Edwards C | 2012 | USA | II-2 /Longitudinal | 24 | RYGB, GB, Sleeve Gastrectomy | WOMAC, KOOS | Mobility, MSK pain |
| Lidar Z | 2012 | Israel | II-2/Longitudinal | 30 | LGBa, SG, LRYGB, DS | SF-36, MA, VAS (pain) | MSK pain |
| Magee CJ | 2011 | UK | II-2/Longitudinal | 68 | LSG | Not used | MSK pain |
| Richette P | 2011 | France | II-2/Longitudinal | 44 | LRYGB, LAGB | WOMAC | Mobility, MSK pain |
| Scozzari G | 2010 | Italy | II-2/Longitudinal | 150 | LVBG | BAROS | Mobility, MSK pain |
| Khoueir P | 2009 | USA | II-2/Longitudinal | 38 | LRYGB, ORYGB, DS, SG | SF-36 | Mobility, MSK pain |
| Brancatisano A | 2008 | Australia | II-2/Longitudinal | 838 | SAGB | SF-36 | Mobility, MSK pain |
| Hooper MM | 2007 | USA | II-2/Longitudinal | 48 | LRYGB, ORYGB | SF-36 | Mobility, MSK pain |
| Korenkov M | 2007 | Germany | II-2/Longitudinal | 145 | LAGB | Numeric Rating Scale for Knee Pain | MSK pain |
| Cottam D | 2006 | USA | II-2/Longitudinal | 126 | LSG followed by LRYGB | Not used | MSK pain |
| Ahroni J | 2005 | USA | II-2/Longitudinal | 179 | LAGB | SF-36 | Mobility, MSK pain |
| Abu-Abeid S | 2005 | Israel | II-2/Longitudinal | 59 | LAGB | American Knee Society Score | Mobility, MSK pain |
| Dittmar M | 2003 | Germany | II-2/Longitudinal | 26 | LGBa | SF-36 | Mobility, MSK pain |
| Schauer P | 2000 | USA | II-2/Longitudinal | 275 | LRYGB | MA QoL questionnaire | Arthritis |
| Parvizi J | 2000 | USA | II-2/Longitudinal | 14 | RYGB, VBG, loop GB, jejunoileal BP | KSS, HHS | Mobility[b] |
| Choban PS | 1999 | USA | II-2/Longitudinal | 36 | RYGB | SF-36 | Mobility, MSK pain |

**Table 1** (continued)

| Author | Year | Country | Quality of evidence*/study type | n | Operation[a] | Validated tool | Outcomes |
|---|---|---|---|---|---|---|---|
| Murr MM | 1995 | USA | II-2/Longitudinal | 62 | VBG, RYGB | Not used | Arthritis |
| McGoey BV | 1990 | Canada | II-2/Longitudinal | 104 | VBG | Not used | MSK pain |
| Trofa D | 2013 | USA | II-3/Retrospective | 15 | RYGB, LAGB | Not used | Arthritis |
| Liu J | 2012 | USA | II-3/Retrospective | 192 | LAGB | AORC | MSK pain |
| Crémieux PY | 2010 | France | II-3/Retrospective | 5,502 | VBG, ORYGB, LRYGBP, LAGB, LGB | Not used | MSK pain, arthritis |
| Peluso L | 2007 | USA | II-3/Retrospective | 400 | RYGB | Not used | MSK pain, arthritis |
| Raftopoulos I | 2005 | USA | II-3/Retrospective | 825 | RYGB | Not used | Arthritis |
| Schoepel KL | 2001 | USA | II-3/Retrospective | 85 | ORYGB | Modified BAROS | MSK pain |

*AORC* assessment of obesity-related co-morbidities, *BP* bypass, *CT* controlled trial (non-randomised), *DS* duodenal switch, *GB* gastric bypass, *Gba* gastric banding, *HBD* human body diagram, *HHS* Harris Hip Score, *KOOS* Knee Osteoarthritis Outcome Score, *KSS* Knee Society Score, *LAGB* laparoscopic adjustable gastric banding, *LDS* laparoscopic duodenal switch, *LGB* laparoscopic gastric bypass, *LGBa* laparoscopic gastric banding, *LRYGB* laparosopic Roux-en-Y gastric bypass, *LRYiGB* laparosopic Roux-en-Y isolated gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *LVBG* laparoscopic vertical banded gastroplasty, *MSK* musculoskeletal, *n* sample population size, *ORYGB* open Roux-en-Y gastric bypass, *RCT* randomised controlled trial, *RYGB* Roux-en-Y gastric bypass, *RYiGB* Roux-en-Y isolated gastric bypass, *SAGB* Swedish Adjustable Gastric Band, *SG* sleeve gastrectomy, *SMFA* Short Musculoskeletal Function Assessment, *TGUG* Timed Get Up and Go, *VBG* vertical banded gastroplasty, *WOMAC* Western Ontario and McMaster Universities Index of Osteoarthritis, *X-S* cross-sectional study

[a] Where not specified, further detail on whether open/laparoscopic was not given

[b] Validated tools may also cover MSK pain, but further breakdown not specified

in bodily pain 3 months after surgery [26], 1 showed a worsening in pain between 1 and 5 years post-operatively [32], and 2 showed higher pain in the surgical group compared to population norms after 5-year follow-up [28]. The remaining 42 results all confirmed statistically significant improvements in bodily or regional pain up to at least 5 years post-operatively [27, 31, 35–37, 41, 43, 45, 48, 51–53, 57, 58, 60–62, 66, 67].

## Arthritis

Six studies in this review investigated the impact of bariatric surgery on arthritis based on author-specified surrogates [34, 42, 46, 50]. These include the following: symptoms of arthritis, reduction in arthritis medication requirements and reduction in symptoms of arthritis based on a questionnaire. One paper retrospectively investigated the incidence of arthroplasty in post-operative groups stratified for rate of weight loss [65]. The individual components of the six studies' results were deconstructed to provide 13 individual results (Table 4). Follow-up ranged from 1 to 9 years.

Of the 13 individual results, 5 did not include any information on statistical significance [50, 63, 67, 68]. All five individual results showed an improvement in arthritis between 1 and 4 years post-operatively. Further breakdown of one result by Schauer et al. showed that whilst most patients within this study had improved arthritis surrogates at 1 year post-operatively, 2 % actually reported a worsening [63].

Of the remaining eight results that did include data on statistical significance, four demonstrated a significant reduction in arthritis (based on a surrogate marker) between 3 and 5 years post-operatively [34, 42]. One result showed an improvement in symptoms in two surgical groups (low BMI vs control) but no statistically significant intergroup difference [46].

Only two results could possibly be construed as negative. Cremieux et al. reported an increased prevalence of acquired MSK deformity at 3-year follow-up, although the remainder of their results had a tendency towards a reduction in arthritis [34]. Trofa et al. subset analysed their post-operative group in terms of rate of weight loss. They suggested that a rate of weight loss greater than 0.6 $kg/m^2$/month may be a risk factor for joint arthroplasty post-operatively ($p<0.001$) [65].

## Weight Loss and Procedure Type

Tables 5, 6 and 7 refer to all results listed in ascending order of time to follow-up and, where specified, expanded to include data on the procedure type and rate of weight loss. A total of 112 individual results were listed. Of these, 41 results included data on weight loss obtained at different times to data relating to the outcome measures. Therefore, a linked analysis of

**Table 2** Physical function studies outcomes, listed in chronological order

| Author | Results | Significance | Follow-up |
|---|---|---|---|
| Zhang N | LSG group, 69.7 % improvement in MSK symptoms | Not specified | 1 month |
| Zhang N | LRYGB group, 83.6 % improvement in MSK group | Not specified | 1 month |
| Nguyen NT | Physical role improvement of 37 % at 1 month and 71 % at 3 months in lap group | Not specified | 1, 3 months |
| Nguyen NT | Physical role reduction by 51 % at 1 month and a 105 % improvement at 3 months in open group | Not specified | 1, 3 months |
| Nguyen NT | Physical function improvement of 31 % at 1 month and 72 % at 3 months in lap group | Not specified | 1, 3 months |
| Nguyen NT | Physical function improvement of 15.8 % at 1 month and 69.5 % at 3 months in open group | Not specified | 1, 3 months |
| Nguyen NT | Physical function, physical role and body pain in lap group no different to normal population | >0.05 | 3 months |
| Abu-Abeid S | 14.5 % improvement in knee function | <0.001 | 3 months |
| Dziurowicz-Kozłowska A | 83.8 % improvement in mobility (longitudinal group) | 0.0002 | 3 months |
| Vincent HK | 22.1 % surgical patients perceived no limitation in walking ability | 0.013 | 3 months |
| Vincent HK | 11.2 % surgical patients perceived no limitation in stair climb | 0.05 | 3 months |
| Vincent HK | No difference in FAP score | 0.317 | 3 months |
| Vincent HK | Increase in self-selected walking speed of surgical group (+15 cm/s) | 0.018 | 3 months |
| Vincent HK | Greater increase in fastest walking speed in surgical group compared to non-surgical (+7 cm/s vs +5 cm/s) | 0.05 | 3 months |
| Vincent HK | Improvement in physical function (+11.5 vs −6.5) | 0.01 | 3 months |
| Vincent HK | No difference in physical role (+7.7 vs −.04) | 0.606 | 3 months |
| Vincent HK | Improvement in physical component score (+11.8 vs 0.0) | 0.003 | 3 months |
| Julia C | 35.6 % improvement in physical function component of SF-36 | $p<0.05$ | 3 months |
| Julia C | 22.6 % improvement in physical role component of SF-36 | $p<0.05$ | 3 months |
| Nguyen NT | No significant difference in physical function between open and lap group at 3 and 6 months (values not specified) | Not specified | 3, 6 months |
| Nguyen NT | Physical role and body pain in open group no different to normal population (values not specified) | >0.05 | 6 months |
| Richette P | 46.6 % reduction in WOMAC stiffness score | <0.0001 | 6 months |
| Richette P | 56.7 % reduction in WOMAC function score | <0.0001 | 6 months |
| Dziurowicz-Kozłowska A | 67.2 % improvement in mobility (cross-sectional groups) | <.0001 | 6 months |
| Zhang N | LSG group, 83.9 % reduction in MSK symptoms | Not specified | 6 months |
| Zhang N | LRYGB group, 88 % reduction in MSK symptoms | Not specified | 6 months |
| Julia C | 51.5 % improvement in physical function component of SF-36 | $p<0.05$ | 6 months |
| Julia C | 34.5 % improvement in physical role component of SF-36 | $p<0.05$ | 6 months |
| Iossi M | 2.37 second improvement in TGUG | $p=0.05$ | 6 months |
| Iossi M | 62.6 % improvement in physical component of SF-36 | $p=0.05$ | 6 months |
| Iossi M | 45.8 % improvement in SMFA bother component | $p=0.05$ | 6 months |
| Iossi M | 47.7 % improvement in SMFA function component | $p=0.05$ | 6 months |
| Edwards C | Improvement of 2.33 in WOMAC stiffness score and 17.76 WOMAC physical function score | $p=0.0001$ | 6 months |
| Edwards C | Improvement in the following KOOS scores: symptoms (8.64), daily living (13.43), sports (15.76), QoL (15.8) | $p<0.003$ | 6 months |
| Hooper MM | Physical function improvement of 48.6 % | <0.001 | 6–12 months |
| Hooper MM | Physical role limitations improvement of 42.1 % | <0.001 | 6–12 months |
| Zhang N | LSG group, 66.7 % reduction in MSK symptoms | Not specified | 1 year |
| Zhang N | LRYGB group, 79.4 % reduction in MSK symptoms | Not specified | 1 year |
| Julia C | 60.3 % improvement in physical function component of SF-36 | $p<0.05$ | 1 year |
| Julia C | 43.7 % improvement in physical role component of SF-36 | $p<0.05$ | 1 year |
| Iossi M | 3.045 second improvement in TGUG | $p=0.05$ | 1 year |
| Iossi M | 52.5 % improvement in physical component of SF-36 | $p=0.05$ | 1 year |
| Iossi M | 55.7 % improvement in SFMA bother component | $p=0.05$ | 1 year |

**Table 2** (continued)

| Author | Results | Significance | Follow-up |
|---|---|---|---|
| Iossi M | 53.1 % improvement in SFMA function component | $p=0.05$ | 1 year |
| Edwards C | Improvement of 2.95 in WOMAC stiffness score and 19.2 in WOMAC physical function score | $p<0.0001$ | 1 year |
| Edwards C | Improvement in the following KOOS scores: symptoms (11.66), daily living (17.36), sports (22.43), QoL (18.5) | $p<0.0001$ | 1 year |
| Ahroni J | Improvement of 34.8 % in physical function component of SF-36 | $p<0.0001$ | 1 year |
| Ahroni J | Improvement of 84.2 % in physical role component of SF-36 | $p<0.0117$ | 1 year |
| Schouten R | 77.9 % improvement in physical abilities in VBG | <0.01 | 1 year |
| Schouten R | 74.4 % improvement in mobility control in VBG | <0.01 | 1 year |
| Schouten R | 87.1 % improvement in mobility range in VBG | <0.01 | 1 year |
| Schouten R | 40.8 % improvement in physical abilities in LABG | <0.01 | 1 year |
| Schouten R | 65 % in mobility control in LABG | <0.01 | 1 year |
| Schouten R | 76.2 % in mobility range in LABG | <0.01 | 1 year |
| Khoueir P | Improved physical functioning (value not specified) | <0.0001 | 1 year |
| Khoueir P | Improved physical role (value not specified) | 0.001 | 1 year |
| Brancatisano A | Improvement in physical function at 13 months | <0.001 | 13 months |
| Brancatisano A | Improvement in physical role at 13 months | <0.001 | 13 months |
| Dittmar M | Improvement in physical functioning (value not specified) | <0.01 | 17 months[a] |
| Dittmar M | Improvement in physical role limitations (value not specified) | <0.05 | 17 months[a] |
| Choban PS | Physical function improved (values not specified) | <0.05 | 18 months |
| Choban PS | Physical role improved (values not specified) | <0.05 | 18 months |
| Parvizi J | Improvement of 43.7 % in KSS | $p<0.01$ | 23 months[a] |
| Parvizi J | Improvement of 68.8 % in HHS | $p<0.05$ | 23 months[a] |
| Grans R | 134 % improvement in physical function component of SF-36 | $p<0.001$ | 2 years |
| Grans R | 203 % improvement in physical role component of SF-36 | $p<0.001$ | 2 years |
| Søvik TT | 62.8 % and 64.6 % improvement in physical function in GB and DS patients, respectively | Not specified | 2 years |
| Søvik TT | 60.6 % and 40.9 % improvement in role limitations due to physical health in GB and DS patients, respectively | Not specified | 2 years |
| Strain GW | IWQOL-Lite physical function worsened from year 1 to 5 (−22.2 %) | 0.07 | 5 years |
| Strain GW | Physical function score worsened from year 1 to 5 (−24.9 %) | 0.004 | 5 years |
| Strain GW | Physical role score worsened from year 1 to 5 (37.3 %) | 0.01 | 5 years |
| Strain GW | Physical component score worsened from year 1 to 5 (−13.1 %) | 0.001 | 5 years |
| Aftab H | 63.3 % improvement in physical component of SF-36 | $p<0.01$ | 5 years |
| Aftab H | 57.4 % improvement in physical role component of SF-36 | $p<0.01$ | 5 years |
| Sanchez-Santos R | Mobility worse in surgical group compared to non-operative group (values not specified) | 0.042 | ≥5 years |
| Sanchez-Santos R | No difference in physical activity of surgical group in patients with and without depression (values not specified) | 0.217 | ≥5 years |
| Mathus-Vliegen EM | No difference in mobility in male patients compared to Dutch norm | Not significant | 8 years |
| Mathus-Vliegen EM | Mobility worse in female patients compared to Dutch norms (values not specified) | <0.001 | 8 years |
| Scozzari G | 75.6 % reported improved physical activity | Not specified | 10 years |

[a] Mean follow-up, expressed to the nearest month

weight loss and outcome measures was not possible for these 41 entries.

Of the 112 results, 40 were exclusively gastric band procedures and 62 were non-banded procedures, which included all gastric bypasses, stapled gastroplasties and duodenal switches, and 10 results pertained to studies with a mixture of banded and non-banded procedures.

A variety of tools were used to assess weight loss; however, for sake of clarity, only absolute weight loss (kg), BMI (either proportion change or absolute values), percentage excess weight loss (%EWL) and percentage excess BMI loss (%EBMIL) were listed. The range of change in BMI was −6.3 to −20.86, %EWL 18.4–83.2 and %BMIL 9.3–77.8.

**Table 3** Musculoskeletal pain studies outcomes, listed in chronological order

| Author | Pain | Significance | Follow-up | Region |
|---|---|---|---|---|
| Zhang N | LSG group, 69.7 % reduction in MSK symptoms | Not specified | 1 month | Not specified |
| Zhang N | LRYGB group, 83.6 % reduction in MSK group | Not specified | 1 month | Not specified |
| Nguyen NT | Body pain improved by 16.1 % at 1 month and 47.2 % at 3 months in lap group | Not specified | 1, 3 months | Not specified |
| Nguyen NT | Body pain worsened by 7.4 % at 1 month and 39.8 % improvement at 3 months in open group | Not specified | 1, 3 months | Not specified |
| Julia C | 38.1 % improvement in body pain component of SF-36 | $p<0.05$ | 3 months | Not specified |
| Abu-Abeid S | 14.7 % improvement in knee pain symptoms | <0.001 | 3 months | Knee |
| Vincent HK | No difference in bodily pain (+8.5 vs +2.9) | 0.539 | 3 months | Not specified |
| Cottam D | 44 % of subjects had resolved back pain | Not specified | 6 months | Back |
| Richette P | 51 % reduction in knee pain | <0.0001 | 6 months | Knee |
| Richette P | 49.8 % reduction in WOMAC pain score | <0.0001 | 6 months | Knee |
| Zhang N | LSG group, 83.9 % reduction in MSK symptoms | Not specified | 6 months | Not specified |
| Zhang N | LRYGB group, 88 % reduction in MSK symptoms | Not specified | 6 months | Not specified |
| Julia C | 42.6 % improvement in body pain component of SF-36 | $p<0.05$ | 6 months | Not specified |
| Edwards C | Improvement of 4.82 in WOMAC pain score | $p<0.0001$ | 6 months | Knee |
| Edwards C | Improvement of 17.78 in KOOS pain score | $p<0.0001$ | 6 months | Knee |
| Hooper MM | Significant reduction in MSK symptoms in 9 out of 12 anatomical regions assessed | <.02 | 6–12 months | 9 various regions |
| Hooper MM | WOMAC score improvement of 67 % | NS | 6–12 months | Knee, hip |
| Hooper MM | Bodily pain improvement of 39.6 % | <0.001 | 6–12 months | Not specified |
| Zhang N | LSG group, 66.7 % reduction in MSK symptoms | Not specified | 1 year | Not specified |
| Zhang N | LRYGB group, 79.4 % reduction in MSK symptoms | Not specified | 1 year | Not specified |
| Julia C | 49.3 % improvement in body pain component of SF-36 | $p<0.05$ | 1 year | Not specified |
| Julia C | Reduction in cohort size with knee pain from 60.6 % pre-operatively to 28.2 % | $p<0.001$ | 1 year | Not specified |
| Edwards C | Improvement of 5.293 in WOMAC pain score | $p<0.0001$ | 1 year | Knee |
| Edwards C | Improvement of 19.44 in KOOS pain score | $p<0.0001$ | 1 year | Knee |
| Ahroni J | Improvement of 57.3 % in body pain component of SF-36 | $p=0.0002$ | 1 year | Joint or back pain |
| Ahroni J | 80.8 % of MSK pain patients improved | $p=0.02$ | 1 year | Joint or back pain |
| Ahroni J | 19.2 % of MSK pain patients reported no change in pain | $p=0.02$ | 1 year | Joint or back pain |
| Lidar Z | 77 % improvement axial back pain | <0.001 | 1 year | Back |
| Lidar Z | 87 % improvement in radicular leg pain | <0.001 | 1 year | Leg |
| Lidar Z | Moderate correlation between decrease in BMI and improvement in leg pain r=0.515 | 0.0036 | 1 year | Leg |
| Lidar Z | No change in physical component of SF-36 | Not specified | 1 year | Not specified |
| Magee CJ | 2 % of subjects reported improvement in degenerative joint pain | Not specified | 1 year | Not specified |
| Schouten R | 65.9 % improvement in pain in VBG group | <0.01 | 1 year | Not specified |
| Schouten R | 49.7 % improvement in pain in LAGB group | <0.01 | 1 year | Not specified |
| Khoueir P | Improvement in bodily pain | <0.05 | 1 year | Not specified |
| Khoueir P | Improvement in axial back pain symptoms | 0.015 | 1 year | Back |
| Khoueir P | 44 % decrease in VAS axial back pain | 0.006 | 1 year | Back |
| Khoueir P | 24 % decrease in ODI lumbar symptoms | 0.05 | 1 year | Back |
| Brancatisano A | 70 % had improvement or resolution in joint pain | Not specified | 13 months | Not specified |
| Brancatisano A | Improvement in body pain | <0.001 | 13 months | Not specified |
| Peluso L | 34 % of patients with pre-operative MSK pain reported resolution in symptoms | $p<0.05$ | 13 months[a] | Back/extremity |
| Peluso L | 41 % of patients with pre-operative MSK pain reported improvement in symptoms | Not specified | 13 months[a] | Back/extremity |
| Dittmar M | Pain in arms and legs reduced by 19.2 % | 0.012 | 17 months[a] | upper limbs, lower limbs |
| Choban PS | Bodily pain improved (values not specified) | <0.05 | 18 months | Not specified |
| Liu J | Improvement of 1.2 (50 %) in AORC score | $p<0.0001$) | 19 months | Not specified |

**Table 3** (continued)

| Author | Pain | Significance | Follow-up | Region |
|---|---|---|---|---|
| Liu J | 51 % of patients had complete resolution in knee pain | Not specified | 19 months | Not specified |
| McGoey BV | 89 % of patients had complete relief of pain in one or more joints | Not specified | 23 months[a] | Back, hip, knee, ankle, foot |
| McGoey BV | 82 % of sufferers of back pain had complete resolution | Not specified | 23 months | Back |
| McGoey BV | 82 % of sufferers of hip pain had complete resolution | Not specified | 23 months[a] | Hip |
| McGoey BV | 75 % of sufferers of knee pain had complete resolution | Not specified | 23 months[a] | Knee |
| McGoey BV | 94 % of sufferers of ankle pain had complete resolution | Not specified | 23 months[a] | Ankle |
| McGoey BV | 95 % of sufferers of foot pain had complete resolution | Not specified | 23 months[a] | Foot |
| Alsabrook GD | 40.5 % reduction in number of CAD patients with symptoms of degenerative joint disease | 0.0001 | 2 years | Not specified |
| Alsabrook GD | 37.5 % reduction in number of CHF patients with symptoms of degenerative joint disease | 0.0001 | 2 years | Not specified |
| Melissas J | 65.5 % of patients with pre-op LBP had complete resolution | Not specified | 2 years | Back |
| Melissas J | 34.5 % of patients with pre-op LBP had reduction in symptoms | Not specified | 2 years | Back |
| Peltonen M | Knee and ankle pain in female group significantly improved compared to normal population | <0.001 | 2 years | Knee, ankle |
| Søvik TT | 56.7 % and 16.6 % improvement in bodily pain in GB and DS patients, respectively | Not specified | 2 years | Not specified |
| Melissas J | 87.5 % of morbidly obese arthritis suffers had complete resolution of arthritis symptoms and 12.5 % had improved symptoms | Not specified | 2 years | Not specified |
| Melissas J | 18.8 % of super obese arthritis sufferers had complete resolution, 68.7 % had some improvement, and 12.5 % had no change in symptoms | Not specified | 2 years | Not specified |
| Schoepel KL | 66.2 % of back pain sufferers had improvement in symptoms between 1 and 3 years post-op | Not specified | 3 years | Back |
| Schoepel KL | 26 % of back pain sufferers had no change in symptoms between 1 and 3 years post-op | Not specified | 3 years | Back |
| Schoepel KL | 7.8 % of back pain sufferers had worsening of symptoms between 1 and 3 years post-op | Not specified | 3 years | Back |
| Grans R | 70 % improvement in body pain component of SF-36 | $p<0.001$ | 3.5 years | Back, hip, knee, ankle |
| Grans R | Significant improvements in hip, knee, ankle and lumbar pain scores | $p<0.05$ | 3.5 years | Back, hip, knee, ankle |
| Korenkov M | 9 % reduction in patients with significant knee pain | <0.001 | 3–8 years | Knee |
| Strain GW | Body pain score worsened from year 1 to 5 (−23.8 %) | 0.02 | 5 years | Not specified |
| Aftab H | 54.1 % improvement in body pain component of SF-36 | $p<0.01$ | 5 years | Not specified |
| Peltonen M | Knee pain in male group significantly improved compared to normal population (values not specified) | <0.01 | 6 years | Knee |
| Peltonen M | Ankle pain in male group significantly improved compared to normal population (values not specified) | <0.05 | 6 years | Ankle |
| Peltonen M | Knee pain in female group significantly improved compared to normal population | <0.005 | 6 years | Knee |
| Peltonen M | Ankle pain in female group significantly improved compared to normal population | <0.001 | 6 years | Ankle |
| Mathus-Vliegen EM | Pain higher in male patients <50 years old compared to Dutch norm, but no difference in >50 | 0.031 | 8 years | Not specified |
| Mathus-Vliegen EM | Pain higher in female patients compared to Dutch norms | <0.001 | 8 years | Not specified |
| Scozzari G | 47.4 % had improved OA pain | Not specified | 10 years | Not specified |

[a] Mean follow-up, expressed to the nearest month

## Discussion

The quality of the papers in this review was moderate, with only 5 of the 43 studies being prospective controlled trials, of which only 3 were randomised. However, to our knowledge, this is the most thorough systematic review of this subject matter in the literature. Other notable reviews of musculoskeletal disease outcomes in bariatric surgery patients include the works of Speck et al. [69] and Gill et al. [70], who include 16 and 6 studies in their data syntheses, respectively.

The results of this review are likely to achieve external validity in the developed world, as the majority of the papers were conducted within Europe or North America and covered a wide variety of bariatric procedures.

**Table 4** Arthritis studies outcomes, listed in chronological order

| Author | Arthritis | Significance | Follow-up |
|---|---|---|---|
| Choi J | Reduction in symptoms of arthritis in 27.1 % of low BMI group compared to reduction of 18.6 % in control group | Not significant | 1 year |
| Schauer P | 23 % of patients had pre-operative DJD. Of these 2 % worsened, 10 remained unchanged, 47 % improved and 41 % resolved | Not specified | 1 year[a] |
| Peluso L | 19 % of patients with self-reported arthritis reported resolution in condition | Not significant | 13 months[b] |
| Peluso L | 54 % of patients with self-reported arthritis reported improvement in condition | Not specified | 13 months[b] |
| Raftopoulos I | Of patients with pre-operative BMI <70, 72.8 % reported improvement in condition | Not specified | 18 months |
| Raftopoulos I | Of patients with pre-operative BMI ≥70, 78.9 % reported improvement on condition | Not specified | 18 months |
| Crémieux PY | Reduced prevalence of MSK disease (−4.9 %) | <0.05 | 3 years |
| Crémieux PY | Reduced prevalence of arthropathy (6 %) | <0.05 | 3 years |
| Crémieux PY | Increased prevalence of osteopathy, chondropathy and acquired MSK deformity (+3.7 %) | <0.05 | 3 years |
| Murr MM | Reduction in medication for arthritis | Not specified | 4 years |
| Sampalis JS | Reduced incidence of arthritis compared to Quebec matched non-surgical group (0.97 % vs 1.72 %) | 0.08 | 5 years |
| Sampalis JS | Reduced medical treatment for arthritis compared to Quebec matched non-surgical group (11.6 % vs 15.77 %) | 0.001 | 5 years |
| Trofa D | Rapid weight loss (−0.6 kg/m2/month) may be a risk factor for joint arthroplasty | $p$<0.001 | Variable, up to 9 years |

[a] Mean follow-up, expressed to the nearest month

[b] Minimum follow-up, further detail not provided

Fifteen of the 43 studies did not utilise a validated outcome tool, and the remaining 28 studies used a variety of 24 different tools. Of the papers that did use a validated tool, only four papers used the BAROS [39, 44] or Moorehead-Ardelt questionnaire [31, 63] tools created specifically for bariatric surgery patients. Although these questionnaires achieved high validity and compared favourably with other established tools, like the SF-36, the heterogeneity of the results and tools used to generate them made statistical analysis impossible.

The results of the impact of bariatric surgery on physical function are generally positive. Table 3 shows that the improvements in function are seen as early as 1 month post-operatively and sustained for up to 10 years, reflecting bariatric surgery's position as the most effective and long-lasting weight-reducing method. The results of the paper by Strain et al. did show that the three cohort groups, investigated at the same time and divided into 1-year, 3-year and 5-year follow-up, respectively, showed a worsening physical capacity with prolonged post-operative follow-up. The three studies that demonstrated no worsening in physical function in comparison to population norms may be considered positive results, as any obesity-related impairment had effectively been eliminated. The studies that showed a worse result in comparison to population norms and non-surgical controls, respectively, did not offer absolute intragroup values, and hence, it is impossible to assess the impact of surgery on these cohorts independently. It is possible that these results may have demonstrated a significant intragroup improvement in physical function that may be lost in the authors' method of reporting.

The pain scores were much more unequivocal, with 68 of the 75 individual results demonstrating an improvement in pain, although 26 of these results did not specify statistical significance. The improvement in pain was reported as early as 1 month and sustained up to 10 years post-operatively. Vincent et al. [26] reported no difference in bodily pain in their cross-sectional study, although the pain score had improved in the cohort undergoing surgery. A similar effect was seen in the study by Lidar et al. [31]. Hooper et al. [36] showed an improvement in the WOMAC pain score in their longitudinal study although this did not achieve statistical significance.

Reporting on arthritis in this review was challenging, as only one of the six studies that listed arthritis as an outcome used a validated tool [63]. It was difficult to determine on what grounds arthritis was evaluated on, and it is likely that clinical surrogates such as pain, stiffness and loss of function may have allowed this section to be discussed under the other outcomes of this review (physical function and pain). Nonetheless, five of the six studies showed a general improvement in arthritis (however assessed) between 1- and 5-year follow-up. To our knowledge, Trofa et al. are unique in the literature by suggesting that a rate of weight loss greater than 0.6 kg/m$^2$/month may be a risk factor for joint arthroplasty post-operatively ($p$<0.001). As all 15 of the patients in their study had pre-operative evidence of osteoarthritis, they do not believe that rapid weight loss is a cause for total joint replacement but could be a risk factor for it in view of the improved physical capacity adding additional strain on chronically damaged joints [65].

**Table 5** Overview of all results expressed in chronological order up to 1 year, procedure type, weight loss and change in musculoskeletal symptoms (where specified)

| Author | Procedure type | Weight loss | Result | Significance[a] | Follow-up | Summary result |
|---|---|---|---|---|---|---|
| Zhang N | Non-banded | %EBMIL | LSG group 10.2, LRYGB group 9.3 | Not significant (between groups) | 1 month | Improvement in MSK symptoms and physical outcome in both groups, LSG > LRYGB |
| Vincent HK | Mixed | BMI | Bariatric group −7.9, non-surgical group +0.5 | $p$<0.0001 | 3 months | Improvement in physical function, no difference in bodily pain |
| Dziurowicz-Kozłowska A | Non-banded | BMI | −21 % in longitudinal group | | 3 months | Improvement in physical function in longitudinal group |
| Abu-Abeid S | Band | BMI | −6.3 | $p$<0.001 | 3 months | Improvement in knee symptoms |
| Nguyen NT | Non-banded | %EWL | LGB group 37, open GB group 32 | $p$=0.01 | 3 months | Physical function improvement in laparoscopic group. Initial decline then improvement in open group. Body pain improved in laparoscopic group but worsened in open group |
| Choi J | Band | %EWL | Low BMI group 20.3, control 18.4 | Not significant | 3 months | No synchronised outcome measures available |
| Peluso L | Non-banded | %EWL | 40.8 | | 3 months | No synchronised outcome measures available |
| Schoepel KL | Non-banded | %EWL | 29 | | 3 months | No synchronised outcome measures available |
| Iossi M | Non-banded | BMI | −14.74 | $p$=0.05 | 6 months | Improvement in physical function |
| Richette P | Non-banded | BMI | −20 % | $p$<0.0001 | 6 months | Reduction in WOMAC stiffness score, improvement in knee pain |
| Edwards C | Non-banded | BMI | −9.6 | $p$<0.0001 | 6 months | Improvement in physical function and reduction in WOMAC stiffness score, improvement in pain |
| Brancatisano A | Band | BMI | 37 | | 6 months | No synchronised outcome measures available |
| Brancatisano A | Band | %EWL | 32 | | | |
| Schauer P | Non-banded | BMI | −12.84 | | 6 months | No synchronised outcome measures available |
| Schauer P | Non-banded | %EWL | 52.8 | | | |
| Hooper MM | Non-banded | BMI | −15 | | 6–12 months | Improvement in physical function, improvement in pain scores |
| Nguyen NT | Non-banded | %EWL | LGB group 54, open GB group 45 | $p$<0.01 | 6 months | No difference in physical function and body pain scores between laparoscopic and open group |
| Choi J | Band | %EWL | Low BMI group 28.5, control 23.7 | Not significant | 6 months | No synchronised outcome measures available |
| Schoepel KL | Non-banded | %EWL | 40 | | 6 months | No synchronised outcome measures available |
| Zhang N | Non-banded | %EBMIL | LSG group 23, LRYGB group 24.5 | Not significant (between groups) | 6 months | Similar improvements in physical function in both LSG and LRYGB groups |
| Schoepel KL | Non-banded | %EWL | 47 | | 9 months | No synchronised outcome measures available |
| Julia C | Non-banded | %Weight loss | 32 | | 12 months | Improvement in physical function, improvement in body and knee pain |
| Strain GW | Non-banded | BMI | −19.1 | | 12 months | No synchronised outcome measures available |
| Strain GW | Non-banded | %EBMIL | 58.5 | | | |
| Brancatisano A | Band | BMI | 33 | | 12 months | Improvement in physical function, joint and body pain |
| Brancatisano A | Band | %EWL | 47 | | | |
| Schauer P | Non-banded | BMI | −16.75 | | 12 months | Most subjects had an improvement or resolution in symptoms of degenerative joint disease |
| Schauer P | Non-banded | %EWL | 68.8 | | | |

**Table 5** (continued)

| Author | Procedure type | Weight loss | Result | Significance[a] | Follow-up | Summary result |
|---|---|---|---|---|---|---|
| Iossi M | Non-banded | BMI | −17.83 | $p=0.05$ | 12 months | Improvement in physical function |
| Edwards C | Non-banded | BMI | −12.6 | $p<0.0001$ | 12 months | Improvement in physical function and pain scores |
| Lidar Z | Mixed | BMI | −13.1 | $p<0.001$ | 12 months | Improvement in axial and back pain, mild correlation between BMI reduction and leg pain improvement |
| Magee CJ | Non-banded | BMI (median) | −14 | $p<0.001$ | 12 months | Only 2 % of subject reported improvement in degenerative joint pain |
| Khoueir P | Non-banded | BMI | −13.93 (−26.9 %) | $p<0.0001$ | 12 months | Improved physical function, improved body pain, especially back/axial |
| Ahroni J | Band | BMI | −13.5 | | 12 months | Improvement in physical function, improvement in MSK pain |
| Zhang N | Non-banded | %EBMIL | LSG group 30.7, LRYGB group 33.4 | Not significant (between groups) | 12 months | Improvement in physical function and pain (LSG > LRYGB) |
| Alsabrook GD | Non-banded | %EBMIL | CAD group, 69.9, CHF group 62.4, control 70.6 | $p=0.0001$ | 12 months | No synchronised outcome measures available |
| Nguyen NT | Non-banded | %EWL | LGB group 68, open GB group 62 | Not significant | 12 months | No synchronised outcome measures available |
| Choi J | Band | %EWL | Low BMI group 44.7, control 30 | $p=0.03$ | 12 months | Similar reductions in arthritis symptoms in both low BMI and control groups |
| Melissas J | Band | %EWL | Morbidly obese group 74.17, super obese group 56 | | 12 months | No synchronised outcome measures available |
| Cottam D | Non-banded | %EWL | 45 post-LSG, then 55 % 6 months post-second stage LRYGB | | 12 months | No synchronised outcome measures available |
| Ahroni J | Band | %EWL | 45.7 | | 12 months | Improvement in physical function, improvement in MSK pain |
| Peluso L | Non-banded | %EWL | 73.4 | | 12 months | Improvement in MSK pain and self reported arthritis |
| Raftopoulos I | Non-banded | %EWL | Higher in morbidly obese group compared to super obese group, further detail not specified | | 12 months | No synchronised outcome measures available |
| Schoepel KL | Non-banded | %EWL | >50 | | 12 months | No synchronised outcome measures available |
| Murr MM | Non-banded | %EWL | 45 in VBG group (peak weight loss) | | 12 months | No synchronised outcome measures available |

*BMI* body mass index, *EBMIL* excess BMI loss, *EWL* excess weight loss, *GB* gastric bypass, *LGB* laparoscopic gastric bypass, *LRYGB* laparosopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *MSK* musculoskeletal

[a] Empty cell indicates information regarding significance not specified by author

**Table 6** Overview of all results expressed in chronological order from 1 to 2 years, procedure type, weight loss and change in musculoskeletal symptoms (where specified)

| Author | Procedure type | Weight loss | Result | Significance[a] | Follow-up | Summary result |
|---|---|---|---|---|---|---|
| Choban PS | Non-banded | BMI | −16 | | 18 months | Improvement in physical function and bodily pain |
| Choban PS | Non-banded | %EWL | 63 | | | |
| Dittmar M | Band | BMI | −6.9 | $p<0.01$ | 18 months | Improvement in physical function, improvement in limb pain |
| Schauer P | Non-banded | BMI | −17.62 | | 18 months | No synchronised outcome measures available |
| Schauer P | Non-banded | %EWL | 71.8 | | | |
| Choi J | Band | %EWL | Low BMI group 42.2, control 42.3 | Not significant | 18 months | No synchronised outcome measures available |
| Murr MM | Non-banded | %EWL | 58 in RYGB group (peak weight loss) | | 18 months | No synchronised outcome measures available |
| Raftopoulos I | Non-banded | %EWL | 54.1 in morbidly obese group, 51.3 % in super obese group | | 18 months | Both morbidly and super obese groups reported improvement in arthritis symptoms (SO > MO) |
| Liu J | Band | BMI | −7.7 | | 19 months | Improvement in AORC score and knee pain |
| Liu J | Band | %EWL | 23.3 | | | |
| Liu J | Band | %EWL | Correlation between %EWL and change in AORC score for OA | Correlation=−0.341, CI=[−0.454, −215], $p<0.0001$ | | |
| Parvizi J | Mixed | BMI | −20 | | 23 months | Improvement in physical function |
| McGoey BV | Band | Weight loss | 44 | | 23 months | Improvement in body, joint and axial pain |
| Søvik TT | Mixed | Weight loss | GBa group −50.6, DS group −73.5, Mean difference between groups 23 kg | $p<0.001$ | 2 years | Similar improvement in both GB and DS groups, improvements in body pain (GB > DS) |
| Søvik TT | Mixed | BMI | −17.3 in GBa group, −24.8 in DS group, mean difference between groups 7.44 | $p<0.001$ | | |
| Søvik TT | Mixed | %body weight loss | GBa group 31.2, DS group 44.8 | | | |
| Brancatisano A | Band | BMI | 32 | | 2 years | No synchronised outcome measures available |
| Brancatisano A | Band | %EWL | 52 | | | |
| Melissas J | Band | %EWL | Morbidly obese group 75, super obese group 59 | | 2 years | Majority of morbidly obese subjects had complete resolution of arthritis symptoms, and majority of super obese subjects had improvements in arthritis symptoms |
| Melissas J | Band | %EWL | 52.3 in operative group | | | |
| Schauer P | Non-banded | BMI | −20.86 | | 2 years | No synchronised outcome measures available |
| Schauer P | Non-banded | %EWL | 83.2 | | | |
| Peltonen M | Mixed | Weight loss | 29.5 kg in male surgical group, 27.6 kg in female surgical group | | 2 years | Significant improvements in knee and ankle pain in female group |
| Melissas J | Band | BMI | −33.6 % in operative group | | 2 years | Improvement in lumbar symptoms |
| Alsabrook GD | Non-banded | %EBMIL | CAD group 73.7, CHF group 61.8, control 74.6 | $p=0.0001$ | 2 year | Similar improvements in degenerative joint disease in both CAD and CHF groups |
| Peluso L | Non-banded | %EWL | 73 | | 2 years | No synchronised outcome measures available |
| Schoepel KL | Non-banded | %EWL | 55 | | 2 years | No synchronised outcome measures available |

*AORC* Assessment of Obesity-Related Co-morbidities, *BMI* body mass index, *CAD* coronary artery disease, *CHF* congestive heart failure, *DS* duodenal switch, *EBMIL* excess BMI loss, *EWL* excess weight loss, *GBa* gastric band, *RYGB* Roux-en-Y gastric bypass

[a] Empty cell indicates information regarding significance not specified by author

**Table 7** Overview of all results expressed in chronological order from 2 to 10 years, procedure type, weight loss and change in musculoskeletal symptoms (where specified)

| Author | Procedure type | Weight loss | Result | Significance[a] | Follow-up | Summary result |
|---|---|---|---|---|---|---|
| Schauer P | Non-banded | BMI | −20.09 | | 30 months | No synchronised outcome measures available |
| Schauer P | Non-banded | %EWL | 76.7 | | | |
| Brancatisano A | Band | BMI | 32 | | 3 years | No synchronised outcome measures available |
| Brancatisano A | Band | %EWL | 54 | | | |
| Strain GW | Non-banded | BMI | −17.3 | | 3 years | No synchronised outcome measures available |
| Strain GW | Non-banded | %EBMIL | 65.7 | | | |
| Scozzari G | Band | BMI | −15.3 | | 3 years | No synchronised outcome measures available |
| Scozzari G | Band | %EBMIL | 77.8 | | | |
| Scozzari G | Band | %EWL | 65 | | | |
| Melissas J | Band | %EWL | Morbidly obese group 67, super obese group 54 | | 3 years | No synchronised outcome measures available |
| Murr MM | Mixed | %EWL | 33 in VBG group | | 3 years | No synchronised outcome measures available |
| Korenkov M | Band | BMI | −14.2 | | 3–8 years | 9 % reduction in proportion of patients with knee pain |
| Korenkov M | Band | %EBMIL | 61.9 | | | |
| Grans R | Non-banded | BMI | −17.2 | $p<0.001$ | 42 months | Improvement in body, lumbar and extremity pain |
| Trofa D | Non-banded | BMI | Patients undergoing total joint arthroplasty lost 27.9 % more original BMI compared to matched controls | $p=0.049$ | 42 months | No synchronised outcome measures available |
| Melissas J | Band | BMI | Morbidly obese group, <30 from 1 year follow-up | | 4 years | No synchronised outcome measures available |
| Melissas J | Band | BMI | super obese group: always remained >35 from 1 year follow-up | | | |
| Melissas J | Band | %EWL | Morbidly obese group 66, super obese group 53 | | | |
| Strain GW | Non-banded | BMI | −12.2 | | 5 years | Physical function worsened between 1 and 5 years ,body pain worsened from years 1 to 5 |
| Strain GW | Non-banded | %EBMIL | 48 | | | |
| Sampalis JS | Mixed/Not specified | BMI | −32 % in surgical group | $p<0.001$ | 5 years | Reduction in arthritis symptoms and analgesic demand |
| Sampalis JS | Mixed/Not specified | %EWL | 62.1 in surgical group | $p<0.001$ | 5 years | |
| Scozzari G | Band | BMI | −14.2 | | 5 years | No synchronised outcome measures available |
| Scozzari G | Band | %EBMIL | 71.6 | | | |
| Scozzari G | Band | %EWL | 59.9 | | | |
| Aftab H | Non-banded | %EBMIL | 59 in pre-op BMI <50 group ,57 in pre-op BMI >50 group | Not significant | 5 years | Improvement in physical function and body pain |
| Aftab H | Non-banded | %EWL | 60 in pre-op BMI <50 group, 58 in pre-op BMI >50 group | Not significant | | |
| Sanchez-Santos R | Non-banded | %EWL | Patients with %EWL <50 % scored worse in BAROS (28.6 %) than group with %EWL >50 % (74.4 %) | $p=0.016$ | >5 years | Mobility worse in surgical group compared to control |

**Table 7** (continued)

| Author | Procedure type | Weight loss | Result | Significance[a] | Follow-up | Summary result |
|---|---|---|---|---|---|---|
| Sanchez-Santos R | Non-banded | %EWL | Patients with %EWL <50 % scored worse in EuroQol 5D Mobility (44 %) than group with %EWL >50 % (14 %) | $p=0.014$ | | |
| Parvizi J | Non-banded | BMI | −2.5 in all patients post-arthroplasty, except one who regained 80 % of original weight | | >5 years (3.7 years post-arthroplasty) | No synchronised outcome measures available |
| Peltonen M | Mixed | Weight loss | 22.8 kg in male surgical group, 19.7 kg in female surgical group | | 6 years | Improvement in knee and ankle pain in both male and female groups |
| Schouten R | Non-banded | BMI | −30.4 % in VBG group, −25.5 % in LGB group | $p<0.01$ | 7 years | No synchronised outcome measures available |
| Schouten R | Non-banded | %EWL | 69 % in VBG group, 54 % in LGB group | $p<0.05$ | | |
| Mathus-Vliegen EM | Non-banded | BMI | −11.2 | | 8.2 years | Pain higher in male patients >50 years old and female group compared to Dutch norms, but no difference in >50 |
| Mathus-Vliegen EM | Non-banded | %EWL | 45.2 | | | |
| Scozzari G | Band | BMI | −14.2 | | 10 years | Improvement in physical activity and OA pain |
| Scozzari G | Band | %EBMIL | 71.5 | | | |
| Scozzari G | Band | %EWL | 59.8 | | | |
| Trofa D | Non-banded | BMI | −18.8 (−35.4 %) at time of arthroplasty | | Not specified | Rapid weight loss may be a risk factor for joint arthroplasty |
| Crémieux PY | Non-banded | No data specified | | | Not specified | Reduced prevalence of arthropathy and MSK disease, but also increased osteopathy, chondropathy and acquired MSK deformity |

*BMI* body mass index, *EBMIL* excess BMI loss, *EWL* excess weight loss

[a] Empty cell indicates information regarding significance not specified by author

Mechanisms that contribute to reduced physical capacity include muscle weakness, joint stiffness and pain [71]. Pain is perhaps the most modifiable factor of the three, with muscle weakness and joint stiffness, in particular, reflecting more chronic and permanent obesity-related joint changes. This may explain the trends seen in our review of bariatric surgery significantly improving pain over a 10-year follow-up, with more equivocal improvements in physical function.

The range in weight loss, however assessed, was large. The lowest reductions in BMI related to a number of studies that exclusively assessed gastric band procedures, but this finding was not supported by other measures of weight loss and nor by length to follow-up. Despite modest reductions in weight, these studies still reported improvements in musculoskeletal symptoms. The largest changes in %EWL appeared in the study of Melissas et al. [49], in which a comparison of outcomes was performed between morbidly and super obese subjects. Excluding these extremes, there appeared to be no clear trend in quantifiable weight loss, procedure type and change in musculoskeletal symptoms. The majority of findings in this review supported a sustained improvement in musculoskeletal symptoms following obesity surgery. With no method of standardising weight loss quantification, it was not possible for this review to explore a possible correlation between the rate of weight loss and outcomes in musculoskeletal disease, a concept suggested by Trofa et al. who hypothesised that the rate of weight loss may be a risk factor for arthroplasty.

The global economic cost of obesity is huge, with the direct costs alone reported to represent 2–7 % of the total world health cost. [72] With recent data pointing to a moderate incremental cost per quality-adjusted life year of UK £2,000–£4,000 (US $3,200–$6,400, Euro €2,400– €4,900) [73], the ability for laparoscopic bariatric surgery to pay for itself within 1 year [20] and a reduction in state benefit claims by 75 % after 14 months [74], there is a compelling economic argument for bariatric surgery. Despite an increase in bariatric surgery activity, referral rates in the developed world are likely to be low. A recent national cross-sectional survey revealed that 5.4 % of the non-institutionalised population in England met the referral criteria for bariatric surgery [75], yet surgery rates were estimated to be only a third of the NHS benchmark [76]. An Australian paper in 2009 reported a lower than 1 % surgery rate [77]. An Office of Health Economics report estimated that if 25 % of UK eligible patients received bariatric surgery, there would be a UK £1.45 billion (US $2.3 billion, Euro €1.78 billion) increase to the GDP from increased population productivity and reduction in health costs and state benefits [20]. There is clearly a clinical and economic need to ensure that current referral guidelines are more thoroughly implemented.

Referral guidelines are largely based on the 1991 National Institute of Health criteria, which are practically identical to recently published European and NICE guidelines [78–80]. The referral criteria can be loosely summarised as offering surgery to motivated patients with a BMI >40 kg/m$^2$ or >35 kg/m$^2$ with a serious obesity-related co-morbidity. The NIH guidelines were fashioned from the limited available evidence at the time and equate “patient risk” with BMI and the presence of obesity-related co-morbidity, with little consideration of other patient factors such as age, ethnicity, weight distribution and future risk. None of the guidelines specifically mentions projected improvement in mobility as an influencing factor when referring to bariatric surgery, although the European Guidelines lists “severe joint disease” as an obesity-related disorder [79]. In view of the significant economic gains to be had by mobilising a previously morbidly obese workforce, the concept of factoring in physical capacity alongside current criteria when considering bariatric surgery warrants further exploration.

Several studies in our review expanded their patient selection beyond the standard criteria described in the NIH referral guidelines. Some centres operated on patients with BMI 30–35 kg/m$^2$ [46], the “super obese” [49, 68] and patients with certain co-morbidities, such as cardiac failure [48] and low back pain [51]. These studies showed improved results within the context of musculoskeletal pain and HCQoL. This therefore suggests that not only is there a need for a larger number of obese patients to be referred for surgery in accordance with current guidelines, but there is also scope for the referral criteria to be broadened.

## Conclusion

The significant costs of managing obesity can be reduced by bariatric surgery at a small increment in cost per quality-adjusted life year. A proportion of this cost-effectiveness can be attributed to an improvement in physical capacity, although the exact figure is not determinable from our review. Bariatric surgery significantly improved physical function, musculoskeletal pain and arthritis over a period of 10 years in 39 of the 43 studies in our review. The proportion of eligible patients being referred for bariatric surgery is low. This raises the question of whether NICE guidelines should be reviewed to improve referral rate and broaden patient selection.

**Statement of Informed Consent** For this type of study, formal consent is not required. To our knowledge, all studies included in the data synthesis were compliant with local research ethics guidelines.

**Statement of Human and Animal Rights** This article does not contain any studies with human participants or animals performed by any of the authors.

**Conflict of Interest** All authors declare no conflict of interest.

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