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ORIGINAL CONTRIBUTIONS

Validating the Alterable Weight Loss (AWL) Metric with 2-Year Weight Loss Outcome of 500 Patients After Gastric Bypass

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Abstract
Background Percentage alterable weight loss (AWL) is the only known weight loss metric independent of the initial body mass index (BMI), a unique feature ideal for use in weight loss research. AWL was not yet validated. The aim of the study is to validate the AWL metric and to confirm advantages over the excess weight loss (EWL) metric.
Methods AWL is tested with 2-year weight loss results of all primary laparoscopic Roux-en-Y gastric bypass patients operated in our hospital. Nadir results of patients with higher and lower initial BMI are compared (Mann–Whitney; $p<0.05$) using outcome metrics BMI, percentage weight loss (WL), EWL, and AWL, for the whole group, for each gender, and for <40 and ≥40 years separately.
Results Five-hundred patients (401 female) out of 508 (98.4 %) had 2-year follow-up. Of all four metrics, only AWL rendered results not significantly influenced by initial BMI. The AWL outcome is initial BMI independent for both genders and age-groups. Results also confirm that women and younger patients had significantly higher AWL outcome.
Conclusion The recently developed AWL metric, defined as 100%×(initialBMI−BMI)/(initialBMI−13), is now validated. In contrast to the well-known outcome metrics BMI, EWL, and WL, the AWL metric is independent of the initial BMI. It should replace the misleading EWL metric for comparing weight loss results in bariatric research and for expressing the effectiveness of bariatric procedures. This effectiveness does not act on the total body mass, or on the excess part, but on the alterable part, defined as BMI minus 13 kg/m^2 for all adult patients, female, male, young, and old.

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Background

A new weight loss metric was proposed for use in bariatric surgery, with distinct advantages over existing outcome metrics excess weight loss (EWL), body mass index (BMI), and percentage weight loss (WL). Many studies have shown that EWL should be used with caution [1–6]. A recent study on 8,945 patients after laparoscopic Roux-en-Y gastric bypass (LRYGB) surgery from the Bariatric Outcomes Longitudinal Database (BOLD) proved that the EWL metric actually can lead to false conclusions both ways: a true difference in weight-loss was missed, while a true similarity was presented as a significant difference [7]. This corruptive effect of the EWL metric can be caused by any coincidental differences in initial BMI between groups. Another study showed that outcome expressed as BMI and WL is influenced by baseline BMI as well, although to a lesser extent [8]. This influence, however, is not inevitable [5–8]. An alternative metric was found for which this disturbance by initial BMI disappears. This is important because only without this disturbance, weight-loss can be compared in a simple and unequivocal way.

In practical terms, this finding means that weight loss effectiveness of a bariatric operation works just the same for any weight and that, for example, relative weight loss in somebody with a BMI of 75 can be the same as in somebody with a BMI of 35. This might seem contrary to what is known about postoperative weight loss in bariatric literature. If it can be confirmed, however, it would provide a unique feature: it would be ideal for use in weight loss research.

In search of this independent metric, it was found that LRYGB affects a much larger portion of the patient's body

mass than the excess weight alone. This was labeled the alterable part, defined as all body mass minus an inert part, being that portion that is not affected by a decrease of intake or uptake of calories. From studies on starvation in anorexia nervosa and famine, this inert part seemed to be about 10 kg/m^2 [9, 10]. From the study on the BOLD cohort, it was found to be 10 kg/m^2 for women and 17 kg/m^2 for men, but with a compromise of 13 kg/m^2 rendering initial BMI-independent results for both genders as well. Based on these findings, the alternative relative weight-loss metric percentage alterable weight-loss (AWL) was proposed. It is the only weight-loss metric known that is independent of the initial BMI.

The first aim of this study is to validate this metric derived from outcome of 8,945 BOLD subjects, with a different, large cohort of patients unrelated to the BOLD database.

The AWL metric has three features that need confirmation. First, AWL outcome does not depend on the initial BMI, while outcome based on BMI, EWL, and WL does. Second, the compromise inert part of 13 kg/m^2 yields BMI-independent results for both genders, enabling AWL results of different genders to be compared with a common metric. The formula of this common AWL metric is AWL=100%×(initialBMI−BMI)/(initialBMI−13). Third, the inert part is age-independent for adults of both genders.

The AWL results of the BOLD cohort showed that gastric bypass is as effective for lighter and heavier patients, but significantly more effective for women and for patients younger than 40 years (with an overlap for the subgroups of older women and younger men.) Once the AWL would be validated, the second aim of this study would be to check these findings on the effectiveness of LRYGB with respect to gender and age.

Materials and Methods

The Institutional Review Board approved this study. Our hospital in Amsterdam is a European Accreditation Council for Bariatric Surgery-approved Center of Excellence, presently performing approximately 900 bariatric procedures annually, predominantly LRYGB. All patients are screened preoperatively by a multidisciplinary team and are offered lifelong follow-up. All are operated after written informed consent. Surgery is performed by four surgeons. All LRYGB are standardized with estimated sizes: pouch 4×8 cm, biliary limb 50 cm, antecolic/antegastric alimentary limb 150 cm. Both gastrojejunostomy and jejunojejunostomy are linear-stapled side-to-side anastomoses, although in the early years a hand-sewn end-to-side gastrojejunostomy was performed.

Data is collected retrospectively. All patients with primary LRYGB before December 2011 are included, allowing for a postoperative interval of at least 2 years. Data on gender, age at time of operation, initial BMI (defined as BMI at the first preoperative visit in our center) and BMI at any postoperative visit are collected. Nadir BMI is defined as lowest postoperative BMI within 2 years. Three large studies on weight loss outcome of morbid and super obese subjects show the lowest weight after bariatric surgery to be reached within this interval.[8, 11, 12]. Significance of any difference is determined with the Mann–Whitney U test, considering a two-tailed $p<0.05$ significant.

Individual nadir relative weight-loss is calculated with three different relative metrics using the formula 100%×(initialBMI−nadirBMI)/(initialBMI−a), with reference BMI a=0 for WL, a=13 for AWL as proposed by van de Laar, and a=25 for EWL as suggested by Deitel et al [7, 13]. Thus, four datasets of the same nadir outcome are formed for EWL, WL, AWL, and BMI.

The whole group is divided by initial BMI into halves and into quarters. The results of the lighter and heavier halves are compared for each of the four datasets. The same is done for the outer quarters, thus comparing the extremes of the group. Outcome is then considered not significantly influenced by the initial BMI if both comparisons of halves and outer quarters are not significantly different. The AWL metric should generate outcome not significantly influenced by the initial BMI, in contrast to the other metrics.

Subsequently, for each gender subgroup, the AWL results of lighter and heavier halves and outer quarters are compared separately. This is done both with AWL based on the compromise inert part a=13 kg/m^2 for both genders and with AWL based on the gender specific inert parts, a=10 kg/m^2 for female, and a=17 kg/m^2 for male. The AWL metric should generate outcome not significantly influenced by initial BMI for both men and women using not only their specific inert parts a=10 kg/m^2 and a=17 kg/m^2 but also the same inert part a=13 kg/m^2 for both genders as well.

Then, for each age-group of <40 and ≥40 years, the AWL results of lighter and heavier halves and outer quarters are compared separately. The AWL metric should generate outcome not significantly influenced by initial BMI for both age-groups.

If these methods are able to validate all three AWL features, the metric is used to test the influence of age and gender on weight-loss in our cohort. The group is therefore divided in four subgroups by gender and age (<40 and ≥40 years). The AWL outcome per subgroup of younger and older men and women is presented and compared.

Results

From the beginning of our bariatric program in 2007 to 1 December 2011, 508 patients underwent primary LRYGB. None of those patients died within the first year. Eight patients

(1.6 %) could not be reached beyond one year and were lost out of follow-up. Two-year data from the remaining 500 primary LRYGB patients are analyzed. Their mean initial BMI at the first preoperative visit was 44.0 kg/m^2 (34.5–67.6 kg/m^2); their median age at time of operation was 43 years (18–65 years); and 401 patients (80.0 %) were female. The median number of postoperative visits was 5 (2–12). Mean nadir BMI was 28.7 kg/m^2 (18.3–49.2 kg/m^2). The distribution of male and female patients by age-groups and their mean nadir results are listed in Table 1 for BMI, WL, AWL, and EWL. The difference in mean age between female (42.0 years) and male (45.5 years) is significant. The differences in initial BMI and nadir BMI between female and male patients are not significant. The differences in initial BMI and nadir BMI between the 67 patients with a hand-sewn end-to-side gastrojejunostomy and those with a linear-stapled side-to-side gastrojejunostomy are not significant.

Nadir results for the whole group per lighter and heavier halves (H1 and H2) and lightest and heaviest quarters (Q1 and Q4) are presented in Figure 1 for BMI, WL, AWL, and EWL. The data set for which the influence of initial BMI is considered not significant by comparing both halves and outer quarters is the one for AWL only (p=0.18 for halves and p=0.67 for quarters). The combined comparisons of lighter and heavier halves and lightest and heaviest quarters of the three other data sets for BMI, WL, and EWL all show significant differences, indicating a significant influence of initial BMI (WL halves $p<0.05$; all five other comparisons $p<0.001$). For both age-groups, the combined comparisons of halves and outer quarters showed no significant differences in AWL results (all four comparisons $p>0.3$). The same is true for both gender subgroups, not only for the common AWL metric, based on the compromise inert part a=13 kg/m^2 for both genders, but also for both gender-specific AWL metrics based on a=10 kg/m^2 for women and a=17 kg/m^2 for men (female a=13 halves $p>0.05$, all seven other comparisons $p>0.3$). All three features of the AWL metric are therewith confirmed.

Nadir AWL of the female patients is significantly higher than that for the male patients. Nadir AWL of the younger patients is significantly higher than that for the older patients. The difference in nadir AWL between the older female subgroup and the younger male subgroup is not significant (overlap, p=0.72). All three findings on the influence of gender and age on the effectiveness of LRYGB from the BOLD cohort are therewith confirmed.

Conclusions

The AWL metric is now validated. The finding of a common inert part of the body mass of 13 kg/m^2 rendering a weight-loss metric that is independent of the initial BMI for all adult patients, female, male, old or, young, is consistent. The formula of this metric is AWL=100%×(initialBMI−BMI)/(initialBMI−13). It is the only metric known that enables comparing weight-loss free of the influence of baseline weight.

With the AWL metric, it was already established that gastric bypass surgery is more effective in terms of nadir weight-loss in women, compared to men and in younger patients compared to older ones (with an overlap for older women and younger men.) These findings could be confirmed in our cohort as well.

The evidence for this AWL metric from the BOLD group was stronger than from this study, because that cohort was almost 18 times larger and the absence of influence of initial BMI was found within a much wider range of 30–80 kg/m^2, compared to 35–68 kg/m^2 in this study. There is a cohort in which, retrospectively, the AWL metric was not confirmed, in a sample of 168 women that underwent LRYGB in Belgium [5]. That cohort, however, was more than 53 times smaller than the BOLD group and consisted of selected patients only, all female and with initial BMI limited to <60 kg/m^2.

Is there a need for another weight-loss metric? A study on the influence of the basic baseline patient characteristic BMI on relative weight-loss outcome showed that EWL results are distorted by the initial BMI 2.5× more than BMI results, 4× more than WL results, and 100× more than AWL results [8]. In our study, these differences could clearly be visualized as well. Figure 1 shows distinct differences in EWL results, no less than 15% EWL between heavier and lighter halves and

Table 1 Patient characteristics and weight loss outcome. Nadir weight loss of 500 patients within two years after LRYGB, expressed with body mass index (BMI), percentage weight loss (WL), excess weight loss (EWL), and alterable weight loss (AWL) for gender and age subgroups

Gender	Age (years)	n	Initial BMI (kg/m^2)	Nadir BMI (kg/m^2)	Nadir WL (%)	Nadir EWL (%)	Nadir AWL (%)
Total	All	500	44.0	28.7	34.7	82.9	49.5
Female	All	401	44.0	28.5	35.2	83.8	50.1
	<40	160	43.9	27.8	36.7	87.5	52.4
	≥40	241	44.2	29.0	34.1	81.3	48.7
Male	All	99	43.7	29.2	32.8	79.6	47.0
	<40	25	44.2	29.4	33.2	78.2	47.2
	≥40	74	43.5	29.2	32.7	80.0	46.9

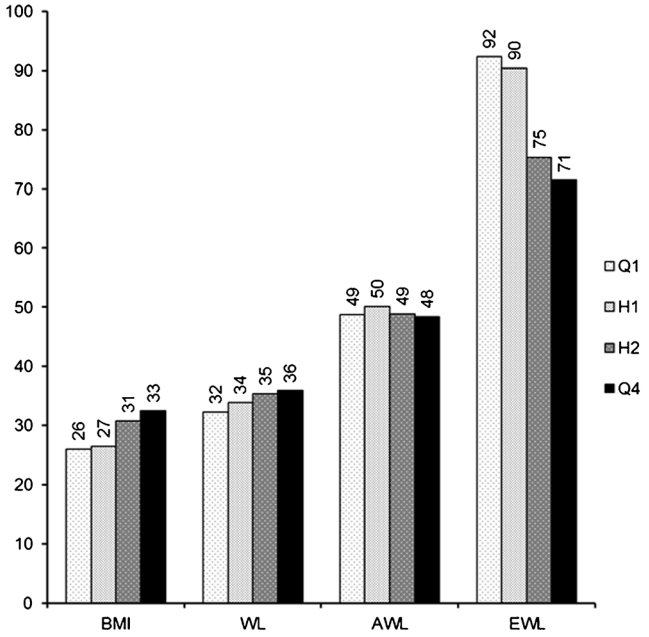

Fig. 1 Mean nadir weight loss results of the lightest quarter (*Q1*), lighter half (*H1*), heavier half (*H2*), and heaviest quarter (*Q4*) of 500 patients after LRYGB, expressed with body mass index (BMI, kg/m^2), weight loss (WL, %), alterable weight loss (AWL, %), and excess weight loss (EWL, %)

even more than 20% EWL between the outer quarters. These differences are less pronounced for BMI and WL results, while hardly visible and statistically not significant for AWL results.

Another study demonstrated that these disturbances of EWL results can actually lead to false conclusions [7]. These mistakes with EWL results are likely to occur if results and differences in results are larger, which typically is the case for bariatric surgery, in contrast to non-surgical weight-loss. To overcome these problems, it was advised to always accompany relative weight-loss results with the absolute results as well, in order to interpret outcome and to be able to scrutinize any conclusions [1, 14]. This makes interpreting results of bariatric studies quite cumbersome, a problem that is often overlooked. Adding a new metric could make things more confusing, unless it would replace this misleading metric EWL altogether.

There are several important advantages of this new AWL metric. First of all, generating outcome free of the influence of initial BMI is ideal for weight-loss research. AWL enables comparing weight-loss in a more straightforward and safe way than with other metrics and without the definite need for keeping the absolute outcome at hand. Second, the fact that AWL results were found to be initial BMI-independent for gastric bypass patients also means that the same bariatric operation is as effective for heavier as for lighter patients, which makes AWL the ideal metric for expressing the effectiveness of a specific bariatric operation. It is interesting to see that this effectiveness does not act on the whole body mass, or on the excess part of the body mass, but on the alterable part, defined as BMI minus 13 kg/m^2 for all adult patients, female, male, young, and old. Furthermore, a metric generating outcome free of the influence of the range of initial BMI can express the outcome with the smallest deviation in results, making it best fit for predicting weight-loss outcome, for example, with the use of a benchmark from large groups of patients. Both in our cohort (n=500) and in the BOLD group (n=8,945), the mean nadir AWL after LRYGB was about 50 %. Then, it takes just a simple calculation to predict somebody's best result after LRYGB, being more or less "the initial BMI minus thirteen, divided by two, plus thirteen."

A review on metabolic surgery showed that improvement of type 2 diabetes is clearly correlated with the amount of relative weight-loss achieved with a type of bariatric procedure, suggesting a direct link between the bariatric effectiveness (i.e., concerning weight-loss) of an operation and the metabolic effectiveness [15]. As AWL now is the metric best fit for determining the bariatric effectiveness, AWL outcome might correlate better with metabolic effectiveness than outcome expressed with other metrics. Further research is needed to confirm this assumption.

It is a disadvantage that the alterable part of one's body is hard to imagine, while the ideas of an absolute result (BMI), a percentage of the total body (WL), or even that of an excess part (EWL) can be understood more easily. For presenting weight-loss, especially to patients, these other metrics are therefore more understandable than AWL. The finding that WL results are least influenced by the initial BMI of all three most widely used metrics EWL, WL, and BMI makes it the best alternative for AWL, although this influence might still play a role when comparing extremes, like morbid obese with

Table 2 Overview of weight loss metrics. Advantages and disadvantages of common weight loss metrics body mass index (BMI), percentage weight loss (WL), excess weight loss (EWL), and the new metric alterable weight loss (AWL)

Metric	Suited for presenting weight loss outcome	Suited for comparing weight loss outcome	Comments
%EWL	+	−	Able to produce false conclusions both ways
%WL	++	+	Less-suited for comparing morbid obese to super obese subjects
%AWL	+	++	Only metric that is independent of initial BMI
BMI	++	+	Only metric directly correlated to health risk

super morbid obese subjects. A major disadvantage of the WL metric is that it does not consider the patient's body length, thus comparing just weight, not body mass. The absolute BMI outcome is clearly influenced by the initial BMI as well. The clinical relevance of an absolute weight-loss result, however, outweighs this disadvantage, as it is important to know which health risk is still present after nadir weight-loss is reached; a risk that can only be expressed by absolute outcome.

A general disadvantage of all these metrics WL, EWL, AWL, and BMI is that they inform on change of body mass only, not on any change in body composition, waist circumference, or hip–waist ratio, measurements more relevant for the metabolic outcome of bariatric surgery.

Any metric should match its purpose. In bariatric surgery, weight-loss metrics can have two purposes: *comparing* results, either mutually, to a benchmark, or with predicted results and *presenting* results, for colleagues or patients. The advantages of each metric in the light of these two purposes are presented in Table 2. In conclusion, EWL can generate misleading outcome and should therefore be abandoned, WL and BMI are ideal for presenting results, while the validated AWL metric could be preferred for comparing results in a scientific way and for expressing the effectiveness of bariatric operations.

Conflict of Interest The authors Arnold van de Laar, Marije Dollé, Maurits de Brauw, Sjoerd Bruin, and Yair Acherman declare that they have no conflict of interest.

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