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ORIGINAL CONTRIBUTIONS

Multi-Centre Micro-Costing of Roux-En-Y Gastric Bypass, Sleeve Gastrectomy and Adjustable Gastric Banding Procedures for the Treatment of Severe, Complex Obesity

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Abstract

Background There is a growing interest in comparing the effectiveness and costs of alternative forms of bariatric surgery. We aimed to examine the per-patient, procedural costs of Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG) and adjustable gastric banding (AGB) in the United Kingdom.

Methods Multi-centre (two National Health Service; NHS and one private hospital) micro-costing, using a time-and-motion study. Prospective collection of surgery times, staff quantities, equipment, instruments and consumables for 12 patients (four RYGB, five SG, three AGB) from patients' first surgeon interaction on the day of surgery to departure from the theatre recovery area. Costs were attached to quantities and mean costs compared. Sensitivity and scenario analyses assessed the impact of varying surgery inputs and consideration of additional plausible factors respectively on total costs.

Results Mean procedural costs were £5002 for RYGB, £4306 for SG and £2527 for AGB. Varying staff seniority or altering procedure times had small impacts on costs (± 4–6%). Reducing prices of consumables by 20% reduced costs by 10–13%. Accounting for differences in surgical technique by altering the number of staple reloads used impacted costs by ± 7–10%. Adjusted total costs from scenario analyses were similar to NHS tariffs for RYGB and SG (difference of £51 and -£119 respectively) but were much lower for AGB (difference of £1982).

Conclusions These detailed costs will allow for more precise reimbursement of bariatric surgery and support comprehensive assessments of cost-effectiveness. Additional work to investigate costs of post-surgical care, re-operations and life-long support received by patients following surgery is required.

Keywords Bariatric surgery · Bottom-up costing · Costs · Cost analysis · Economics · Micro-costing · Reimbursement · Tariffs · Time-in-motion study

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Introduction

Bariatric surgery is often recommended for individuals with severe and/or complex obesity (body mass index; BMI of ≥ 40 kg/m^2 or between 35 and 40 kg/m^2 with significant comorbidities) [1–3]. Three types of bariatric procedures are mainly used, Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG) and a declining number of adjustable gastric banding (AGB) procedures [4]. Importantly, SG has become an increasingly common procedure, accounting for the majority of surgeries performed in some countries [5].

Evidence from observational studies suggest that RYGB and SG offer greater weight reduction and improvement of comorbidities but come with increased risks and less flexibility compared to AGB [6]. However, evidence from comparative randomised controlled trials is limited [7, 8], as is information on the relative cost-effectiveness of the three procedures [9, 10]. To fill these evidence gaps, the By-Band-Sleeve (BBS) randomised controlled trial is being conducted in the UK and is comparing the relative effectiveness and cost-effectiveness of RYGB, SG and AGB [7, 11]. An important part of this trial is to ensure that detailed costs of the three procedures are used in the trial cost-effectiveness analysis.

A recent review [12] identified existing estimates of the procedural costs of RYGB and AGB and noted that many of the analyses failed to consider important cost components (e.g. reporting separate costs for reusable and disposable instruments) and parameters (e.g. accounting for the costs of sterilising reusable instruments) in their estimation. Furthermore, the review did not identify any studies reporting detailed costs for SG. This highlights the need for up-to-date, detailed costings of the three procedures to ensure precise setting of reimbursements, appropriate budgeting by providers and to support comparative assessments of cost-effectiveness.

This paper reports the per-patient procedural costs of RYGB, SG and AGB for the treatment of severe and complex obesity in the National Health Service (NHS) in the UK. We also report procedural costs together with the costs of a pre-operative assessment visit and post-surgery inpatient stay to inform comparisons with NHS tariffs.

Methods

Overview

The procedural costs of bariatric surgery are a function of the resources consumed and their associated unit costs (i.e. the cost for one unit of a particular product or service). The gold standard approach to identifying and valuing resource items is micro-costing (every input consumed to treat a patient is identified) [13] and bottom-up costing (assigning patient-specific unit costs to each resource item) [14] respectively. Ideally, cost data should also be collected from multiple sites to account for variation in estimates [15].

A multi-centre micro-costing study was therefore designed, dividing the approach into eight steps [16, 17] (Appendix A) and conducted within the BBS study [7, 11].

Setting, Cases for Observation and Care Cycle

Three hospitals (one private, site A, and two NHS, sites B and C) located in the south of England were studied to ensure that variability in costs could be examined.

One consultant surgeon at each of the three sites, who was experienced in each of the three procedures, identified at least three cases (one of each procedure) involving BBS patients 18 years of age or older, scheduled to receive either RYGB, SG or AGB as their first bariatric surgery during 2017.

Micro-costing entails very detailed, costly and labour-intensive data collection, but results in the most accurate representation of costs compared to other costing methods [13]. We therefore aimed to measure the costs of the procedures as accurately as possible, but in a relatively small sample. Our target sample size was nine patients in total, one of each procedure at each of the three sites. Marginally increasing our target sample size (e.g. targeting an additional nine patients) would have necessitated costly investment in data collection with potentially no impact on the external validity of our findings. While greatly increasing our target sample size (e.g. 50–100 patients) would reduce the feasibility of using micro-costing methods, ultimately necessitating the use of less accurate costing methods that could compromise the validity of the study findings. We therefore judged our target sample size of nine patients to be sufficient to maximise both the internal and external validity of the study findings. It should be noted that there is no minimum accepted sample size for micro-costing studies, and sample sizes are usually limited given the trade-off between the cost of collecting additional data and increasing the accuracy and validity of the findings [18].

The care cycle summarises the boundaries of the costing analysis, in that resource items consumed within the care cycle are used to determine the total cost of each surgical procedure. The care cycle starts from the patient's first interaction with a surgeon on the day of surgery and finishes when the patient leaves the theatre recovery area. The care cycle was chosen to encompass the majority of resource items used during the surgical procedure but did not include the pre-operative assessment visit or the post-surgery inpatient stay.

Patient and Operational Pathways with Resource Implications

The three bariatric procedures were apportioned into pre-operative, intra-operative and post-operative stages (Fig. 1) to identify observable patient and operational pathways with

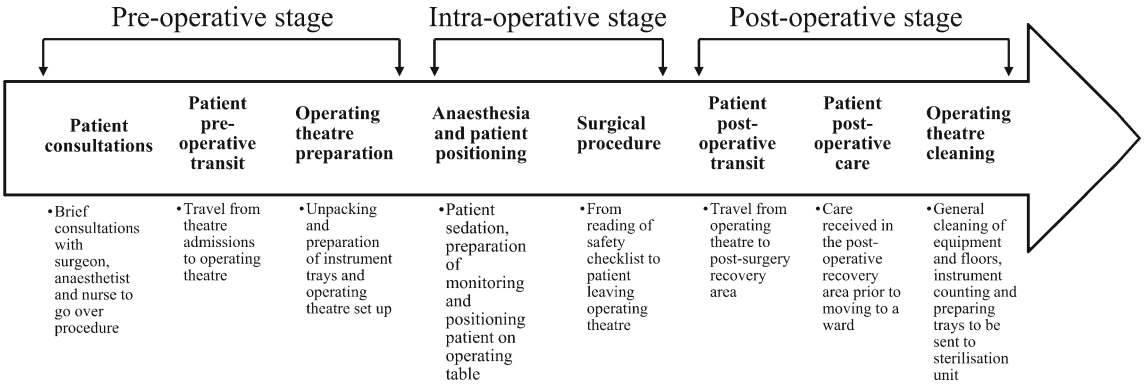

Fig. 1 Observable patient and operational pathways with resource implications. Resource items consumed within each pathway were identified and broadly grouped into four categories, including staff (time of consultants/non-consultants, nursing and other healthcare professionals), theatre (equipment, maintenance and overheads), reusable instruments (including sterilisation) and consumables (medications, disposables, sutures, etc.)

resource implications occurring within the care cycle. Resource items consumed within each pathway were identified and broadly grouped into four categories:

1. Staff (time of consultants/non-consultants, nursing and other allied healthcare professionals)
2. Theatre (equipment, maintenance and overheads)
3. Reusable instruments (including sterilisation)
4. Consumables (medications, disposables, sutures, etc.)

Measuring Resource Quantities and Identifying Unit Costs

Time-and-Motion Study

Direct surgery observation using a time-and-motion study was employed to estimate procedure times, personnel involvement and quantities of resources consumed during the care cycle. One researcher (BD) observed as many of the pathways as possible for each patient, and all three procedures were observed at least once, at each of the three sites. As multiple patients were observed on a single day at sites B and C, it was necessary to devise an algorithm (Appendix B) to ensure all pathways were observed at least once, at each of the three sites, as some of the pathways are overlapping. The algorithm allows the procedure to be observed for all patients but allocates observations for the remaining seven pathways to individual patients where variation in resources consumed are likely to be minimal. Observations of the four procedures at site A were made on three different days, but it was still necessary to follow the algorithm, just across multiple days. Using a stopwatch and standardised data collection form (Appendix C), the observing researcher (BD) recorded the place within the hospital where an activity occurred, the personnel who executed the activity and how much time it took to perform. This allowed for the calculation of the total number of minutes that each type of staff spent providing direct patient care or performing operational activities (e.g. preparation of instrument trays, administrative duties, etc.) (Appendices D and E). The amount and types of medication administered and the number and manufacturer of equipment, re-usable instruments and consumables used within each pathway were also recorded. A summary list of this information is provided in Appendix F.

Resource Use and Cost Questionnaire

To supplement the time-and-motion study, procurement and finance departments at each site were sent a Microsoft Excel 2016 (Microsoft Corporation, Redmond WA)-based spreadsheet requesting unit price information for equipment, reusable instruments and consumables recorded during the time-and-motion observations. Information on the life expectancy of equipment, number of operations per year for which the equipment is used, maximum number of uses for reusable instruments, maintenance and repair costs as well as its frequency for equipment was also requested. A separate questionnaire was also sent to personnel in the sterilisation department at each site requesting information on the staff time, equipment and consumables used in the process of sterilising reusable instruments.

Cost Databases

Access to the NHS Supply Chain online catalogue and ordering system, which acts as the national provider of equipment, instruments and consumables for approximately 10,000 locations throughout the UK was obtained to identify unit cost information [19]. This database provided national average purchase prices for the majority of

reusable instruments and consumables recorded during the surgeries. When required, unit costs were supplemented by site-specific procurement/finance purchase prices collected in the resource use and cost questionnaire. Published national data (e.g., British National Formulary [20], Personal Social Services Research Unit (PSSRU) Unit Costs of Health and Social Care [21], Pay and Conditions Circular [22] and Scottish Health Service Costs [23]) were also used as sources of unit costs for medications, staff and theatre time. All unit costs are expressed as 2017 British Pounds Sterling and a summary list of unit costs is provided in Appendix F.

Costing Models

Cost models for each procedure and patient were developed in Microsoft Excel 2016 based on equations reported by Ismail et al. [24] to calculate the total costs of the four resource categories across all eight pathways.

Staff Costs

The per-patient staff costs were estimated as a function of the number of staff involved in a patient's procedure, the total number of minutes worked by each staff member and the cost per working minute for each type of staff. Note that the cost per working minute for each type of staff includes not only a wage/salary, but also banding supplements (applies to registrars/foundation doctors only), employer's national insurance and superannuation contributions, qualification costs (applies to consultants/registrars only), non-capital overheads (staff training costs, general supplies/services and utilities), capital overheads (office space, recreational and changing facilities) and are adjusted to account for time off due to sickness and training/study [21].

Theatre Costs

The per-patient theatre costs were estimated by multiplying the total number of minutes for which the theatre was used for a patient's procedure (note, this includes four pathways: operating theatre preparation, anaesthesia/patient positioning, procedure and operating theatre cleaning) by a per-minute theatre cost derived from the average theatre costs of 15 health boards (total of 375 hospitals) with hours of theatre usage varying from 17 to 2770 h/week [23]. This cost includes the purchase prices for furniture, fittings and equipment (non-capital charge), administration and clerical staff costs, cleaning, equipment and property maintenance, utilities, rent and capital charges [23].

Reusable Instrument Costs

The per-patient reusable instruments costs were estimated by adjusting the purchase price of each instrument by its maximum number of uses and associated sterilisation costs (in terms of technician's time and any consumables used in the sterilisation process) and then summing the adjusted costs for each instrument used during the eight pathways.

Consumables Costs

The purchase price for each consumable was divided by the number of units contained within a package to establish a per-unit cost. Multiplying the per-unit cost by the number of units consumed during the procedures resulted in the per-patient cost for each consumable. These costs where then summed for all the consumables used during the eight pathways to estimate the total consumables cost.

Total Procedural Costs

Using the costs derived for each resource category, a total per-patient cost estimate for each procedure at each of the three sites was calculated by summing the per-patient costs for staff, theatre, reusable instruments and consumables for each of the eight pathways.

Main and Sensitivity Analyses

Mean costs for both the four separate resource categories and total procedural costs were estimated for each of the three surgical procedures and variation presented as 95% confidence intervals. Analysis of variance (ANOVA) was used to investigate if there was significant variation between the mean costs of the three procedures. In the presence of significant variation between the three groups (i.e. ANOVA results with $p < 0.05$), post hoc paired t tests (two-tailed) were conducted to determine if the mean costs for two of the procedures were significantly different (i.e. comparisons were made between RYGB versus SG, RYGB versus AGB and SG versus AGB). As multiple comparisons were conducted, the Bonferroni correction was applied to compensate for the increased likelihood of a false-positive conclusion (i.e. to maintain a 0.05 type 1 error rate). Statistical significance was assessed at the 0.05 level but adjusted for three comparisons resulting in a significance threshold of 0.0167.

A number of sensitivity analyses were conducted to assess how the total cost results changed when surgery inputs were varied one parameter at a time. These included (i) varying the levels of staff inputs to account for any differences in the grades/qualifications of staff across

sites, (ii) altering procedure times (i.e. time from safety checklist to patient leaving theatre) by ± 20%, (iii) altering NHS Supply Chain list prices for consumables by ± 20% to account for potential discounts that certain hospitals might receive, (iv) altering the estimated cost per minute in the theatre based on minimum and maximum reported values, (v) altering the number of staple reloads used during the RYGB and SG procedures to account for the impact of employing different surgical techniques and (vi) the use of staple line reinforcement (e.g. seam guards) for the SG procedure. Scenario analyses were also conducted to highlight the impact of considering additional plausible factors not considered in the main analysis that may affect the cost of the procedures. Specifically, NHS reference costs [25] were used to calculate the additional costs of a number of different types and potential annual frequencies of outpatient attendances associated with band fills/adjustments, as such events could be considered directly part of the procedure. NHS reference costs [25] were also used to calculate the additional costs associated with a pre-operative assessment visit and post-surgery inpatient stay so that the estimates from the main analysis could be directly compared to NHS tariffs [26].

Results

Main Analysis

A breakdown of the total costs by resource category and patient/operational pathway are presented in Fig. 2a, b respectively. Table 1 presents the per-patient and mean costs overall and for each resource category for the three procedures.

Staff Costs

Mean staff costs were largest for RYGB (£1146; 95% CI £855, £1438), but were not significantly different (p = 0.0625) from the mean costs of SG (£769; 95% CI £559, £980) and AGB (£696; 95% CI £562, £829). Site A consistently had the lowest staff costs, except for AGB, where site B had slightly lower costs (£629 versus £626 respectively). Site C consistently had higher staff costs for all three procedures, with the exception of one RYGB performed at site B (£1293 versus £1493 respectively).

Theatre Costs

Mean theatre costs were not significantly different across the three procedures (p = 0.182) but were slightly larger for RYGB (£711; 95% CI £536, £885) compared to SG (£509; 95% CI £358, £660) and AGB (£489, 95% CI £328, £650). Site A consistently had the lowest and site C the highest theatre costs across the three procedures, the one exception being one RYGB performed at site B that had slightly larger costs compared to site C (£865 versus £831 respectively).

Reusable Instruments Costs

Mean reusable instrument costs were not significantly different across the three procedures (p = 0.471) as each site had very similar costs for each of the three procedures. Site C consistently had the highest reusable instruments costs for all three procedures (range £75–£121), whereas site A had the lowest costs for AGB (£56) and site B had the lowest costs for RYGB (£71) and SG (£51).

Consumables Costs

Mean consumable costs differed significantly across the three procedures (p = 0.0001). In particular, RYGB (£3059; 95% CI £2558, £3560) and SG (£2943, 95% CI £2792, £3093) costs were each significantly higher than AGB (£1274, 95% CI £1112, £1437) costs (p = 0.002 and p = 0.0001 respectively), but mean consumables costs for RYGB and SG were similar (p = 0.643). Variation in the cost of consumables across the three sites for AGB was minimal (range £1121 to £1406). Variation was, however, larger for RYGB (range £2578 to £3772) and SG (range £2744 to £3130).

Total Procedural Costs

Mean total costs differed significantly across the three procedures (p = 0.0001). In particular, RYGB (£5002; 95% CI £4736, £5268) and SG (£4306, 95% CI £3805, £4807) costs were each significantly higher than AGB (£2527, 95% CI £2138, £2915) costs (p = 0.0001 and p = 0.003 respectively), but mean total procedural costs for RYGB and SG were similar (p = 0.062). Variation in total costs across the three sites for each procedure was largest for SG (range £3696 to £5014). The variation in total costs across the three sites for RYGB and AGB was also quite large (ranges £4721 to £5280 and £2158 to £2838 respectively).

The majority of costs were incurred during the procedure (86%, 84% and 73%) and anaesthesia/patient positioning (9%, 9% and 15%) pathways for RYGB, SG and AGB respectively (Fig. 2b), with the remaining pathways contributing only a small proportion to the total procedural costs.

Sensitivity Analyses

The results of the sensitivity analyses are presented in Table 2. Increasing the seniority of clinical support staff involved in the procedures to the highest levels observed across the sites and adding a London multiplier (metric used to account for higher salaries in London) to all consultant costs, increased mean

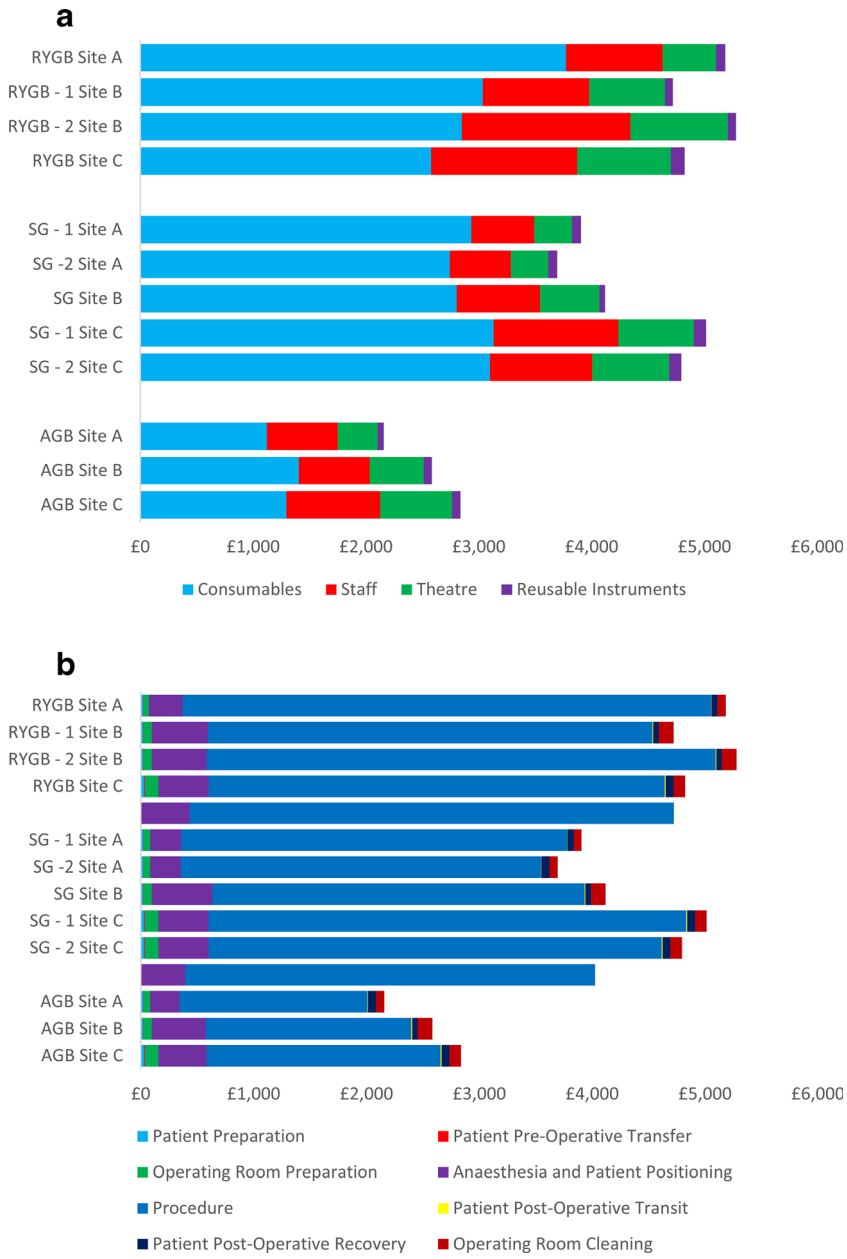

Fig. 2 Breakdown of total procedural costs by **a** resource category and **b** patient/operational pathway. AGB adjustable gastric banding; RYGB Roux-en-Y gastric bypass; SG sleeve gastrectomy. The notation "Site A/B/C-1/2" is used to denote the observation of multiple patients receiving the same procedure at one site. For example, Site B-1 refers to the first patient observed at that site receiving RYGB; site B-2 refers to the second patient observed at that site receiving RYGB. Note that site A is a private healthcare provider and sites B and C are publicly funded hospitals

total costs by £129, £148 and £202 for AGB, SG and RYGB respectively. Altering the unit costs for all consumables by ± 20% resulted in the largest percentage change in mean total costs for SG (± £574; ± 13%), followed by RYGB (± £594; ± 12%) and AGB (± £241; ± 10%). Using the highest reported per-minute theatre cost increased procedural costs by 17–28%, whereas costs decreased by 7–9% when using the lowest per-minute theatre cost. Altering procedure times by ± 20% resulted in the largest percentage change in mean total costs for RYGB (± £285; ± 6%) and AGB (± £150; ± 6%), with SG having a slightly smaller percentage change (± £171; ± 4%). Using ten stapler reloads for the RYGB and SG increased procedural costs by 7 and 9% respectively, whereas using only five stapler reloads decreased procedural costs by 9 and 10% respectively. The use of staple line reinforcement had only a small impact on the procedural costs for SG (+ 3%).

Scenario Analyses

The results of the scenario analyses are presented in Tables 3 and 4. Accounting for the additional costs associated with band fills/adjustments increased mean total cost for AGB by between £178 and £940 (+ 7 to 37%) depending on the type of outpatient attendance (consultant led or non-consultant led), specialty of healthcare professional, number of healthcare

Table 1 Per-patient and mean costs by resource category and overall for the three procedures

RYGB		SG		AGB	
Staff costs					
Site A	£856	Site A-1	£557	Site A	£629
Site B-1	£944	Site A-2	£540	Site B	£626
Site B-2	£1493	Site B	£738	Site C	£832
Site C	£1293	Site C-1	£1106		
		Site C-2	£905		
Mean	*£1146*		*£769*		*£696*
95% CI	*£855 to £1438*		*£559 to £980*		*£562 to £829*
Theatre costs					
Site A	£475	Site A-1	£335	Site A	£352
Site B-1	£670	Site A-2	£331	Site B	£479
Site B-2	£865	Site B	£526	Site C	£636
Site C	£831	Site C-1	£670		
		Site C-2	£683		
Mean	*£711*		*£509*		*£489*
95% CI	*£536 to £885*		*£358 to £660*		*£328 to £650*
Reusable instrument costs					
Site A	£81	Site A-1	£81	Site A	£56
Site B-1	£71	Site A-2	£81	Site B	£72
Site B-2	£71	Site B	£51	Site C	£75
Site C	£121	Site C-1	£107		
		Site C-2	£107		
Mean	*£86*		*£85*		*£67*
95% CI	*£63 to £109*		*£65 to £106*		*£56 to £79*
Consumables costs					
Site A	£3772	Site A-1	£2934	Site A	£1121
Site B-1	£3035	Site A-2	£2744	Site B	£1406
Site B-2	£2850	Site B	£2804	Site C	£1295
Site C	£2578	Site C-1	£3130		
		Site C-2	£3100		
Mean	*£3059*		*£2943*		*£1274*
95% CI	*£2558 to £3560*		*£2792 to £3093*		*£1112 to £1437*
Total procedural costs					
Site A	£5184	Site A-1	£3907	Site A	£2158
Site B-1	£4721	Site A-2	£3696	Site B	£2583
Site B-2	£5280	Site B	£4119	Site C	£2838
Site C	£4823	Site C-1	£5014		
		Site C-2	£4796		
Mean	*£5002*		*£4306*		*£2527*
95% CI	*£4736 to £5268*		*£3805 to £4807*		*£2138 to £2915*

The notation "site A/B/C-1/2" is used to denote the observation of multiple patients receiving the same procedure at one site. For example, site B-1 refers to the first patient observed at that site receiving RYGB, whereas site B-2 refers to the second patient observed at that site receiving RYGB. Note that site A is a private healthcare provider and sites B and C are publicly funded hospitals. The costs presented in the table in italics represent mean costs overall and for each resource category for the three procedures

AGB adjustable gastric banding, *CI* confidence interval, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy

Table 2 Sensitivity analyses on mean total procedural costs for the three procedures

	RYGB		SG		ABG	
	Mean total cost	Percent change	Mean total cost	Percent change	Mean total cost	Percent change
Main analysis	£5002	–	£4306	–	£2527	–
High staff costs	£5204	+ 4%	£4454	+ 3%	£2656	+ 5%
Low staff costs	£4742	− 5%	£4134	− 4%	£2373	− 6%
+ 20% consumables cost	£5596	+ 12%	£4880	+ 13%	£2768	+ 10%
− 20% consumables cost	£4408	− 12%	£3732	−13%	£2285	− 10%
High theatre costs	£6045	+ 21%	£5035	+ 17%	£3245	+ 28%
Low theatre costs	£4664	− 7%	£4034	− 6%	£2294	− 9%
+ 20% procedure time	£5287	+ 6%	£4477	+ 4%	£2677	+ 6%
− 20% procedure time	£4717	− 6%	£4135	− 4%	£2376	− 6%
Use of ten stapler reloads[a]	£5373	+ 7%	£5036	+ 9%	NA	NA
Use of five stapler reloads[a]	£4529	− 9%	£4152	− 10%	NA	NA
Use of staple line reinforcement[b]	NA	NA	£4414	+ 3%	NA	NA
No staple line reinforcement[b]	NA	NA	£4234	− 2%	NA	NA

AGB adjustable gastric banding, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy

[a] The number of staple reloads that were accounted for in the main analysis for the RYGB procedures included 10 for site A, 7 and 6 for patient 1 and 2 respectively at site B and 7 for site C. The number of staple reloads that were accounted for in the main analysis for the SG procedures included 6 and 5 for patient 1 and 2 respectively for site A, 5 for site B and 7 for both patient 1 and 2 for site C. Please refer to Appendix E for further details

[b] Only site C used staple line reinforcement (seam guards) for both patients 1 and 2. Please refer to Appendix F for further details

professionals involved in the attendance and number of attendances in a year.

Accounting for the additional costs of the pre-operative assessment visit and post-surgery inpatient stay increased total mean procedural costs by 15%, 21% and 23% for RYGB, SG and AGB respectively. When the NHS 2017/18 tariffs for the procedures were compared to the respective mean adjusted total costs, the tariff was higher by £51 and £1982 for RYGB and AGB respectively whereas the tariff for SG was £119 less than its mean adjusted total cost.

Discussion

The mean, per-patient procedural costs from our micro-costing were £5002 for RYGB, £4306 for SG and £2527 for AGB. Differences in total costs between the three surgical procedures were mainly attributable to differences in the costs of consumables and staff. The between-site variation in total procedural costs was largest for SG (range £3696 to £5014) followed by AGB (range £2158 to £2838) and RYGB (range £4721 to £5280). Total procedural costs for SG and AGB were consistently higher at the two NHS hospitals (sites B and C), whereas the private hospital (site A) had the second highest cost, behind site B (NHS hospital) for the RYGB procedure. However, given our limited sample, it would be inappropriate to suggest that there might be a difference in the cost of the procedures (particularly SG and AGB) between NHS and private hospitals. Total procedural costs only changed slightly when the surgery inputs were varied in sensitivity analyses, with one exception: using the highest per-minute theatre cost increased total procedural costs by 17–28%. In scenario analyses, we also highlighted that consideration of the additional costs of a pre-operative assessment visit and the post-surgery inpatient stay resulted in adjusted cost estimates for AGB that were much lower than the NHS tariff, even when also accounting for the additional annual cost of band fills/adjustments (difference range £1042 to £1804). In contrast, mean adjusted total costs for RYGB and SG were much closer to their respective tariff (difference of £51 and − £119 respectively), providing some indication that UK tariffs for the RYGB and SG procedures are reflective of the costs incurred by hospitals to perform the surgeries.

Recently, we conducted a systematic review of analyses reporting detailed breakdowns of the procedural costs of any type of bariatric surgery [12]. Compared to costs estimates for either RYGB or AGB reported in the literature (mean US$14,389 or £10,044) our micro-costing estimates are substantially lower. Differences in the estimates are most likely explained by dissimilar care cycles. However, care cycles in the literature were not clearly defined making it difficult to know over what time frame resource items and costs were measured (e.g. it is not

Table 3 Scenario analyses on the mean total procedural costs for adjustable gastric banding accounting for cost of band fills/adjustments

Type of outpatient attendance for band fill/adjustment	Unit cost of outpatient attendance	Assumed number of outpatient attendances in one year	Total one-year band fill/adjustment cost	Adjusted AGB cost (procedure cost plus one-year band fill/adjustment cost)
Consultant led attendances				
Upper gastrointestinal surgery	1st attendance—£171 Follow-up attendance—£131	3	£433	£2960
		6	£826	£3353
Multi-professional with Upper gastrointestinal surgery lead	1st attendance—£170 Follow-up attendance—£154	3	£478	£3005
		6	£940	£3467
Diagnostic imaging	1st attendance—£50 Follow-up attendance—£64	3	£178	£2705
		6	£370	£2897
Multi-professional with Diagnostic imaging lead	1st attendance—£134 Follow-up attendance—£160	3	£454	£2981
		6	£934	£3461
Non-consultant led attendances				
Upper gastrointestinal surgery	1st attendance—£112 Follow-up attendance—£152	3	£416	£2943
		6	£872	£3399
Multi-professional with Upper gastrointestinal surgery lead	1st attendance—£105 Follow-up attendance—£114	3	£333	£2860
		6	£675	£3202
Diagnostic imaging	1st attendance—£31 Follow-up attendance—£172	3	£375	£2902
		6	£891	£3418
Multi-professional with Diagnostic imaging lead	1st attendance—£112 Follow-up attendance—£130	3	£372	£2899
		6	£762	£3289

Note that band adjustments may be done in the x-ray department by a radiologist, potentially accompanied by a nurse or by a bariatric surgeon and/or bariatric specialist nurse at a clinic appointment. Some adjustments might also be conducted by or with support from a dietician. Note that the unit costs of non-consultant led follow-up attendances for both "upper gastrointestinal surgery" and "diagnostic imaging" specialties are larger than their respective consultant-led follow-up attendances. The reason for these counterintuitive differences is not clear but could potentially be due to a combination of longer attendance times as well as the need for additional supervision of non-consultant-led attendances

AGB adjustable gastric banding

clear if costs prior to the day of surgery or after the post-surgery inpatient stay were included in the existing estimates).

Gounder et al. [27] has also reported the cost of RYGB and SG in New Zealand (NZ). Mean operation costs for SG and RYGB were NZ$9131 (£4398) and NZ$12,456 (£6001) respectively and included costs for the surgeon, anaesthetist, theatre, ward doctor, ward, pharmacy and radiology/laboratory/pathology costs. The cost of RYGB was 36% higher than the cost of SG. This difference is much larger than observed in our study (cost of RYGB was 16% higher than SG). Gounder et al. explain the difference is due to longer procedure times for RYGB compared to SG (230 versus 147 min). In our study, the difference in procedure times was much smaller (116 versus 71 min), which might explain our smaller difference in mean total costs for the two procedures.

Our study does have limitations. First, our cost estimates are derived from a relatively small number of observations (12 patients). Generally, there is no minimum accepted sample size for micro-costing studies [18]. Given our micro-costing provides a transparent representation of the actual resources utilised during the three procedures across three sites, it was judged that the cost of conducting additional observations outweighed any potential increase in validity. Second, our analysis did not assess the potentially large cost impact of complications (e.g. anastomotic leaks and respiratory failure/infection) resulting in re-admissions within 30 days of the procedure [28], as the focus of our analysis was specifically on costs incurred during the actual procedure. However, the rates of these events are being recorded in the BBS study and will be an essential aspect of any future economic analysis of bariatric surgery [29]. Third, the availability of site-specific unit cost information was limited, often due to confidentiality concerns. Our analysis therefore relied on purchase prices listed on the NHS Supply Chain online catalogue, which may not reflect prices paid by hospitals capable of negotiating special discounts. Furthermore, aggregated per-minute theatre costs were derived from Scottish hospitals and apportioned to the analysis based on the theatre usage attributed to each patient. Despite theatre equipment information being collected during the observations, it was difficult

Table 4 Scenario analyses on the mean total procedural costs for all three procedures accounting for the cost of the pre-operative assessment visit and post-surgery inpatient stay

Lead for surgery	Case	Main analysis mean total cost (A)	Cost of pre-operative assessment[a] (B)	Cost of post-procedure inpatient stay[b] (C)	Adjusted total cost (A + B + C)	NHS 2017/18 tariff[c]	Difference in tariff and adjusted cost
RYGB							
	Site A	£5184	£141	£615	£5940	£5809	- £131
	Site B-1	£4721	£141	£615	£5477	£5809	£332
	Site B-2	£5280	£141	£615	£6036	£5809	- £227
	Site C	£4823	£141	£615	£5579	£5809	£230
	Mean	*£5002*	*£141*	*£615*	*£5758*	*£5809*	*£51*
SG							
	Site A-1	£3907	£141	£750	£4798	£5078	£280
	Site A-2	£3696	£141	£750	£4587	£5078	£491
	Site B	£4119	£141	£750	£5010	£5078	£68
	Site C-1	£5014	£141	£750	£5905	£5078	- £827
	Site C-2	£4796	£141	£750	£5687	£5078	- £609
	Mean	*£4306*	*£141*	*£750*	*£5197*	*£5078*	*- £119*
AGB							
	Site A	£2158	£141	£428	£2727	£5078	£2351
	Site B	£2583	£141	£428	£3152	£5078	£1926
	Site C	£2838	£141	£428	£3407	£5078	£1671
	Mean	*£2527*	*£141*	*£428*	*£3096*	*£5078*	*£1982*

AGB adjustable gastric banding, *NHS* National Health Service, *RYGB* Roux-en-Y gastric bypass, *SG* sleeve gastrectomy

[a] The cost of the pre-operative assessment visit (i.e. update blood tests, electrocardiogram and hospital swabs for methicillin-resistant *Staphylococcus aureus*) were based on the NHS Reference Cost for a consultant-led, general surgery outpatient attendance

[b] The cost of the post-surgery inpatient stay was derived from the 2016/2017 National Schedule of Reference Costs by multiplying the average length of stay in days (note that this is different for each procedure; 2.03 days for gastric bypass, 2.09 days for sleeve gastrectomy and 1.30 days for gastric band) and the excess cost per bed day associated with elective inpatient admissions assigned healthcare resource groups FF11Z "major surgical procedures for obesity" (£303), FF12Z "sleeve gastrectomy for obesity" (£359) and FF13Z "gastric band procedures for obesity" (£329) for the gastric bypass, sleeve gastrectomy and adjustable gastric band procedures respectively

[c] Note that these values represent the national average tariff and have not been adjusted for differences in unavoidable costs between different providers using the Market Forces Factor (compensates providers facing more than the minimum level of unavoidable costs due to geographic location). However, since the mean total costs derived in the main analysis were based mainly on national average unit costs and not site-specific unit costs, such an adjustment was unnecessary

to obtain parameters required to attribute an equipment cost to each procedure, and thus, the best available estimates were used.

Overall, the results of our study can inform future economic evaluations that compare the relative cost-effectiveness of the three procedures. Such evidence is very limited in the literature [9, 10] and will form a major output of the BBS study. Our methodological approach to costing also provides a framework that can be used by other researchers to estimate detailed procedural costs of bariatric surgery outside the UK because we report our resource items and unit costs separately; therefore, other researchers can adjust our figures to their own setting. This could help facilitate improved estimation of the cost-effectiveness of different approaches to surgery and result in more efficient allocation of limited healthcare resources.

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Compliance with Ethical Standards

Conflict of Interest Author 2 declares receiving support from Ethicon Endo-Surgery for attending conferences and funding a Bariatric Clinical Fellow as well as receiving honoraria from Novo Nordisk. Author 5 received salary funding from the British Heart Foundation. All the other authors have no conflict of interests to declare, except support from a government grant detailed in the acknowledgements.

Ethical Approval The National Research Ethics Committee South West – Frenchay approved the micro-costing on 6th December 2011 as part of the BBS study protocol. All procedures performed in studies involving human participants were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the BBS study.

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