

## Supplementary Material

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### SUPPLEMENTARY MATERIAL

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## Appendix 1: Supplementary Tables

**Table i. Comparison of characteristics between cases linkable to civil registration data (the study cohort) and those unlinkable to civil registration data**

Variable	Linkable to civil registration data (study population) n=12,961 (81.3%)	Unlinkable to civil registration data n=2,984 (18.7%)	p-value
Age [mean (SD)]	73 (11)	72 (11)	0.013
Sex [n (%)]			>0.9
Female	7,063 (54.5)	1,623 (54.4)	
Male	5,898 (45.5)	1,361 (45.6)	
<b>Body mass index [mean (SD); n (%) non-missing]</b>	28.8 (5.2); n=9,355 (72.2)	28.5 (5.2); n=2,134 (71.5)	0.030
<b>ASA grade [n (%)]</b>			<0.001
ASA 1	911 (7.0)	276 (9.2)	
ASA 2	7,808 (60.2)	1,852 (62.1)	
ASA 3+	4,242 (32.7)	856 (28.7)	
<b>Practice setting [n (%)]</b>			<0.001
NHS provider	12,023 (92.8)	1,847 (61.9)	
Independent provider	938 (7.2)	1,137 (38.1)	
<b>Components replaced at revision [n (%)]</b>			
Acetabular & femoral	6,916 (53.4)	1,499 (50.2)	
Acetabular only	3,975 (30.7)	911 (30.5)	
Femoral only	1,806 (13.9)	490 (16.4)	
Head and/or liner only	250 (1.9)	82 (2.7)	
No components replaced	14 (0.11)	2 (0.07)	
<b>Bone graft use at revision [n (%)]</b>			
Acetabular bone grafting	3,211 (24.8)	621 (20.8)	
Femoral bone grafting	296 (2.3)	71 (2.4)	
Acetabular & Femoral bone grafting	408 (3.1)	93 (3.1)	
No bone grafting	9,046 (69.8)	2,199 (73.7)	
<b>Lead &amp; assistant surgeon grade [n (%)]</b>			
Consultant assisted by non-consultant	11,530 (89.0)	2,799 (93.8)	
Consultant assisted by consultant	455 (3.5)	84 (2.8)	
Non-consultant assisted by consultant	729 (5.6)	75 (2.5)	
Non-consultant assisted by non-consultant	247 (1.9)	26 (0.87)	
<b>Intra-operative complication [n (%)]</b>			
No intra-operative complication recorded	12,519 (96.6)	2,900 (97.2)	
Intra-operative complication recorded	442 (3.4)	84 (2.8)	

Comparison of characteristics between cases linkable to civil registration data (the study cohort) and those unlinkable to civil registration data after application of National Joint Registry and data quality exclusions (see main article Figure 1). Between group statistical tests used: age - Wilcoxon test, Body Mass Index - Student's t-test, Chi-square test for categorical variables. RHR = revision hip replacement; ASA = American Society of Anaesthesiologists; NHS = National Health Service.

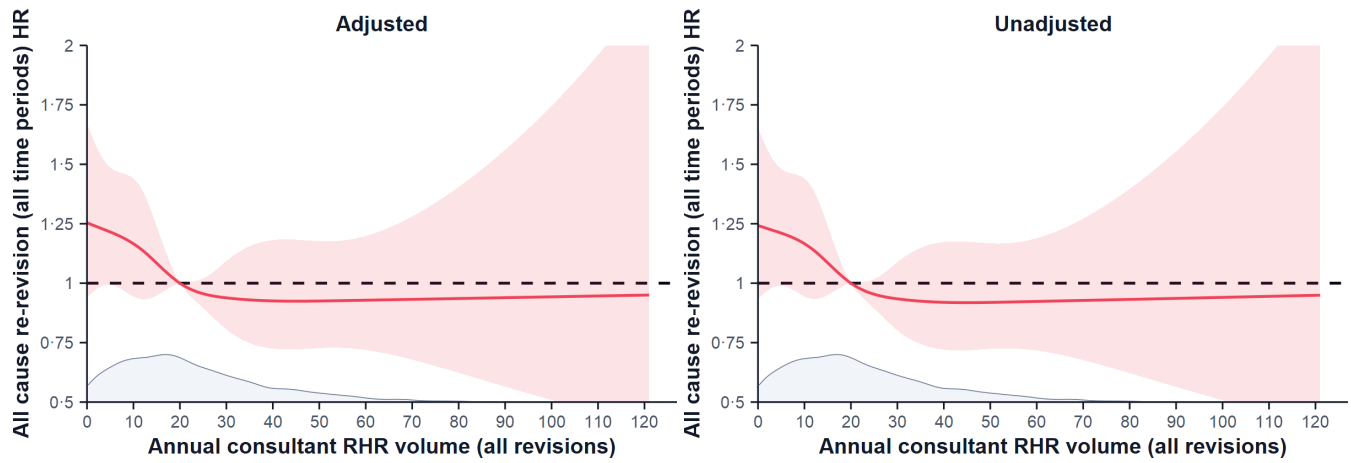
## Appendix 2: Association between surgical volume and all cause re-revision (all time periods)

### Annual consultant RHR volume (all revisions)

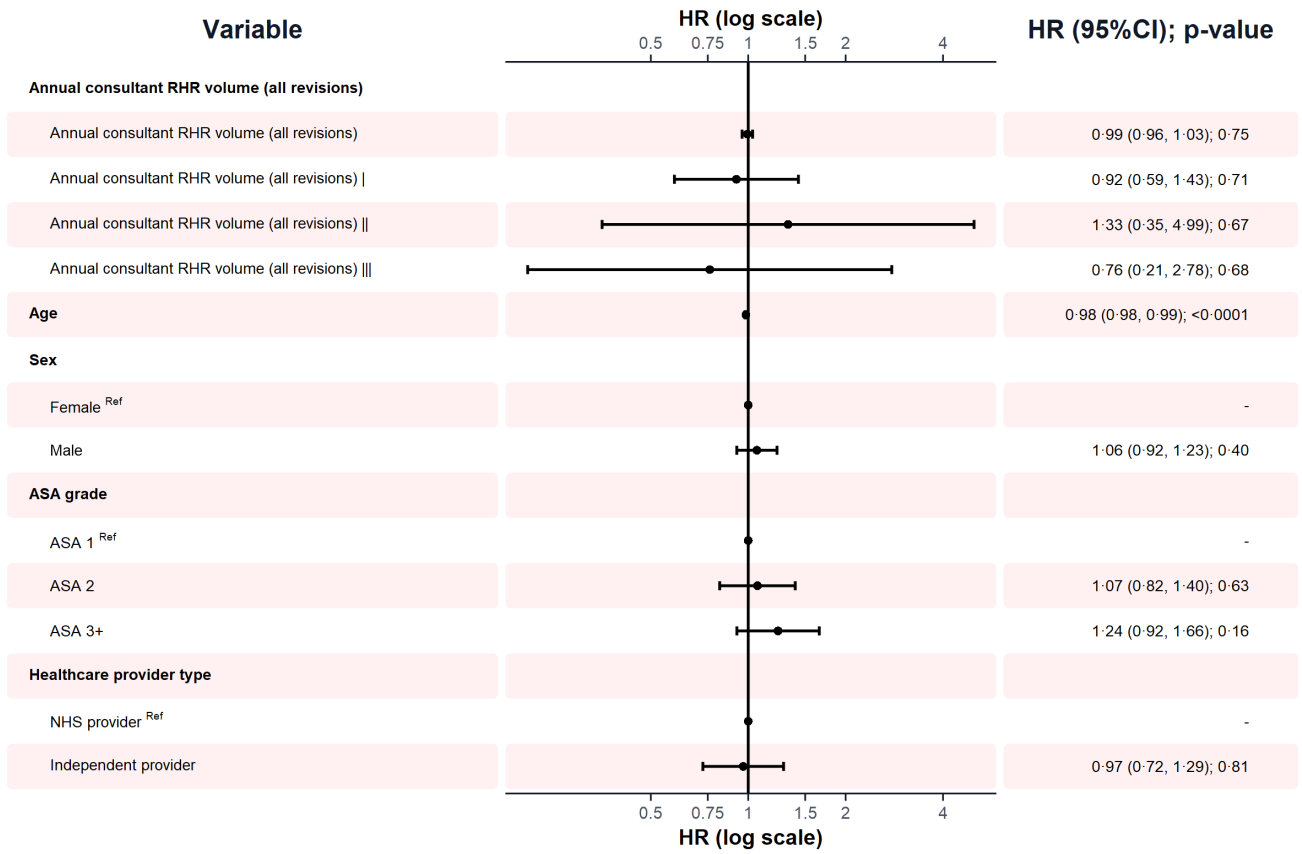
Table ii. Characteristics of study cohort by annual consultant RHR volume (all revisions) group

Variable	Annual consultant RHR volume (all revisions)					All cases
	0 to 5 n=1,395 (10·8%)	6 to 14 n=3,112 (24·0%)	15 to 27 n=4,390 (33·9%)	28 to 46 n=2,859 (22·1%)	47 to 121 n=1,205 (9·3%)	
Age [mean (SD)]	72·9 (11·0)	72·9 (10·8)	72·6 (11·1)	72·3 (11·2)	72·1 (11·0)	72·6 (11·0)
Sex [n (%)]						
Female	752 (53·9)	1,633 (52·5)	2,406 (54·8)	1,594 (55·8)	678 (56·3)	7,063 (54·5)
Male	643 (46·1)	1,479 (47·5)	1,984 (45·2)	1,265 (44·2)	527 (43·7)	5,898 (45·5)
Body mass index [mean (SD)]	29·1 (5·2)	29·0 (5·3)	28·8 (5·2)	28·7 (5·1)	28·2 (5·3)	28·8 (5·2)
ASA grade [n (%)]						
ASA 1	87 (6·2)	195 (6·3)	299 (6·8)	216 (7·6)	114 (9·5)	911 (7·0)
ASA 2	840 (60·2)	1,844 (59·3)	2,603 (59·3)	1,732 (60·6)	789 (65·5)	7,808 (60·2)
ASA 3+	468 (33·5)	1,073 (34·5)	1,488 (33·9)	911 (31·9)	302 (25·1)	4,242 (32·7)
Practice setting [n (%)]						
NHS provider	1,261 (90·4)	2,961 (95·1)	4,188 (95·4)	2,628 (91·9)	985 (81·7)	12,023 (92·8)
Independent provider	134 (9·6)	151 (4·9)	202 (4·6)	231 (8·1)	220 (18·3)	938 (7·2)
Components replaced at revision [n (%)]						
Acetabular & femoral	602 (43·2)	1,625 (52·2)	2,498 (56·9)	1,589 (55·6)	602 (50·0)	6,916 (53·4)
Acetabular only	486 (34·8)	950 (30·5)	1,263 (28·8)	865 (30·3)	411 (34·1)	3,975 (30·7)
Femoral only	263 (18·9)	468 (15·0)	537 (12·2)	366 (12·8)	172 (14·3)	1,806 (13·9)
Head and/or liner only	39 (2·8)	66 (2·1)	88 (2·0)	38 (1·3)	19 (1·6)	250 (1·9)
No components replaced	5 (0·36)	3 (0·10)	4 (0·09)	1 (0·03)	1 (0·08)	14 (0·11)
Bone graft use at revision [n (%)]						
Acetabular bone grafting	296 (21·2)	778 (25·0)	1,153 (26·3)	704 (24·6)	280 (23·2)	3,211 (24·8)
Femoral bone grafting	26 (1·9)	82 (2·6)	104 (2·4)	74 (2·6)	10 (0·83)	296 (2·3)
Acetabular & Femoral bone grafting	34 (2·4)	82 (2·6)	149 (3·4)	109 (3·8)	34 (2·8)	408 (3·1)
No bone grafting	1,039 (74·5)	2,170 (69·7)	2,984 (68·0)	1,972 (69·0)	881 (73·1)	9,046 (69·8)
Lead & assistant surgeon grade [n (%)]						
Consultant assisted by non-consultant	1,252 (89·7)	2,833 (91·0)	3,896 (88·7)	2,498 (87·4)	1,051 (87·2)	11,530 (89·0)
Consultant assisted by consultant	85 (6·1)	144 (4·6)	158 (3·6)	53 (1·9)	15 (1·2)	455 (3·5)
Non-consultant assisted by consultant	28 (2·0)	98 (3·1)	282 (6·4)	239 (8·4)	82 (6·8)	729 (5·6)
Non-consultant assisted by non-consultant	30 (2·2)	37 (1·2)	54 (1·2)	69 (2·4)	57 (4·7)	247 (1·9)
Intra-operative complication [n (%)]						
No intra-operative complication recorded	1,342 (96·2)	2,973 (95·5)	4,239 (96·6)	2,780 (97·2)	1,185 (98·3)	12,519 (96·6)
Intra-operative complication recorded	53 (3·8)	139 (4·5)	151 (3·4)	79 (2·8)	20 (1·7)	442 (3·4)

Cases were grouped approximately into thirds (tertiles) of annual consultant RHR volume (all revisions). To compare case characteristics at the extremes of surgical volume, the lower and upper tertiles were further subdivided by identifying cases representing the bottom and top 10% of the distribution (unless the skewness precluded this). RHR = revision hip replacement; ASA = American Society of Anaesthesiologists; NHS = National Health Service.



**Figure a.** Adjusted and unadjusted marginal association of change in annual consultant RHR volume (all revisions) with risk of all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

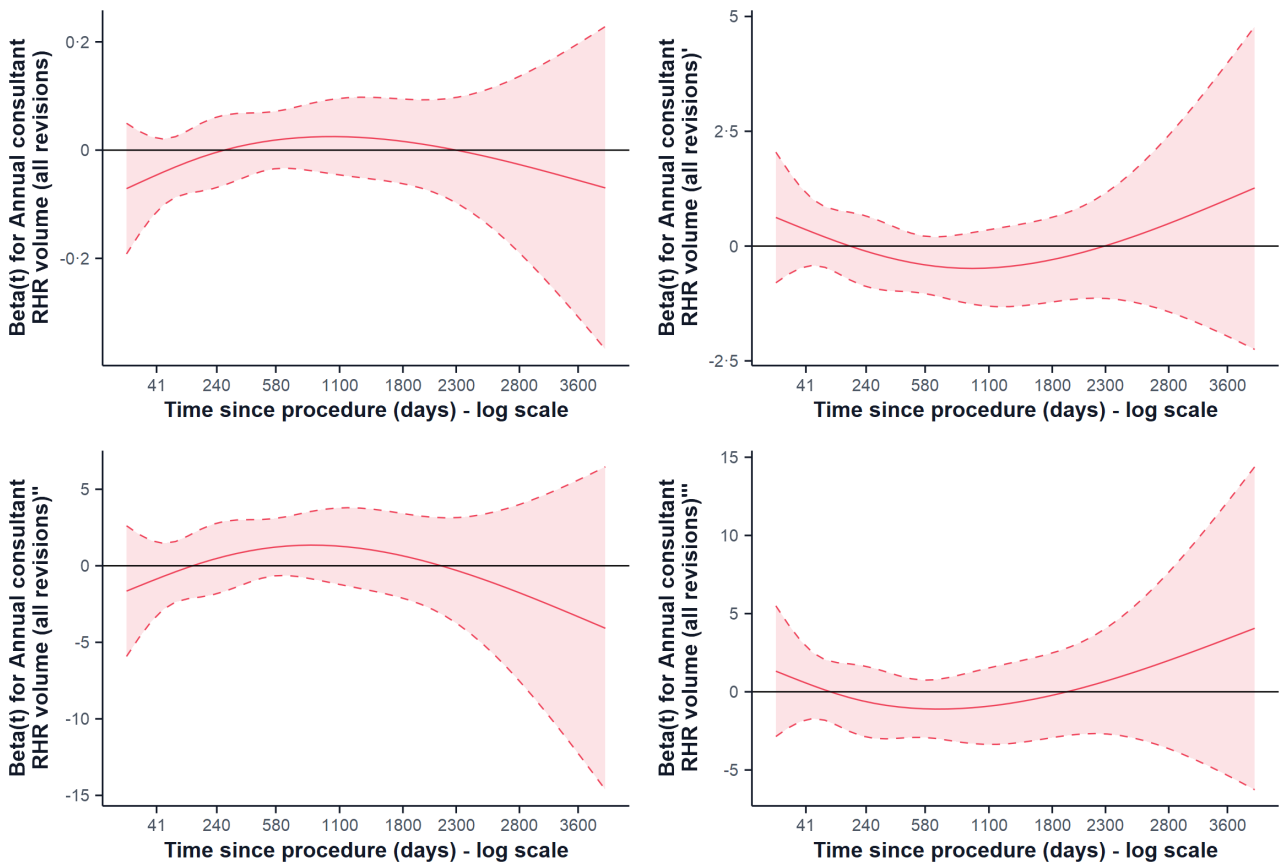


**Figure b.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S1. Number of observations = 12,961. Number of events = 756. R squared = 0.00275. Akaike information criterion (AIC) = 13,628.

**Table iii. Tests of proportional hazards assumptions for annual consultant RHR volume (all revisions) restricted cubic spline term**

Parameter	p
Annual consultant RHR volume (all revisions)	0.668
Annual consultant RHR volume (all revisions)'	0.434
Annual consultant RHR volume (all revisions)''	0.376
Annual consultant RHR volume (all revisions)'''	0.322

Table showing the results of formal testing of proportional hazards for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model.



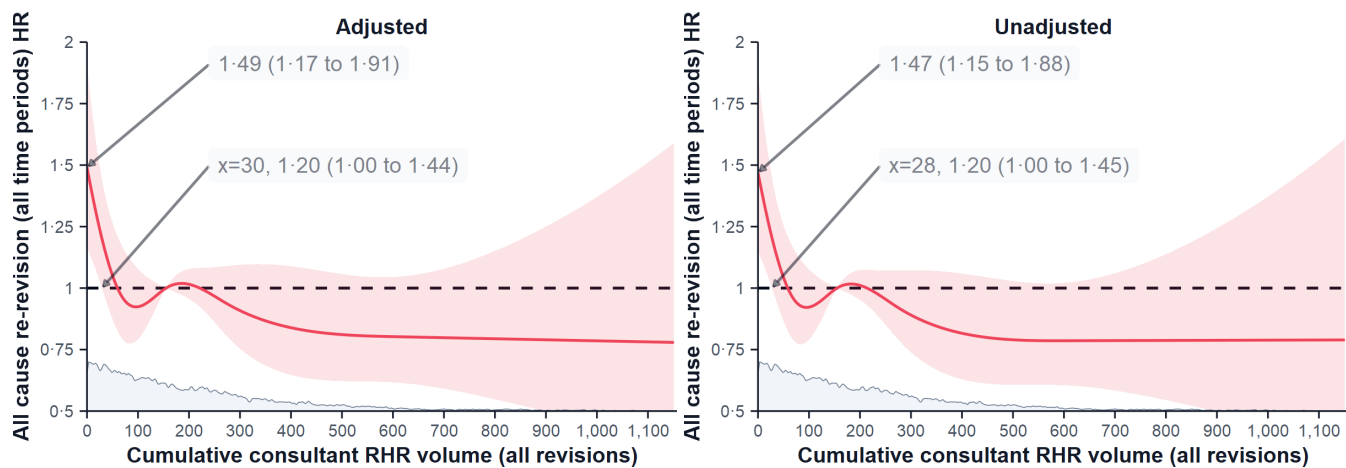
**Figure c.** Plot of the smoothed scaled Schoenfeld residuals for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model. Shaded area indicates the 95% confidence interval.

**Cumulative consultant RHR volume (all revisions)**

**Table iv. Characteristics of study cohort by cumulative consultant RHR volume (all revisions) group**

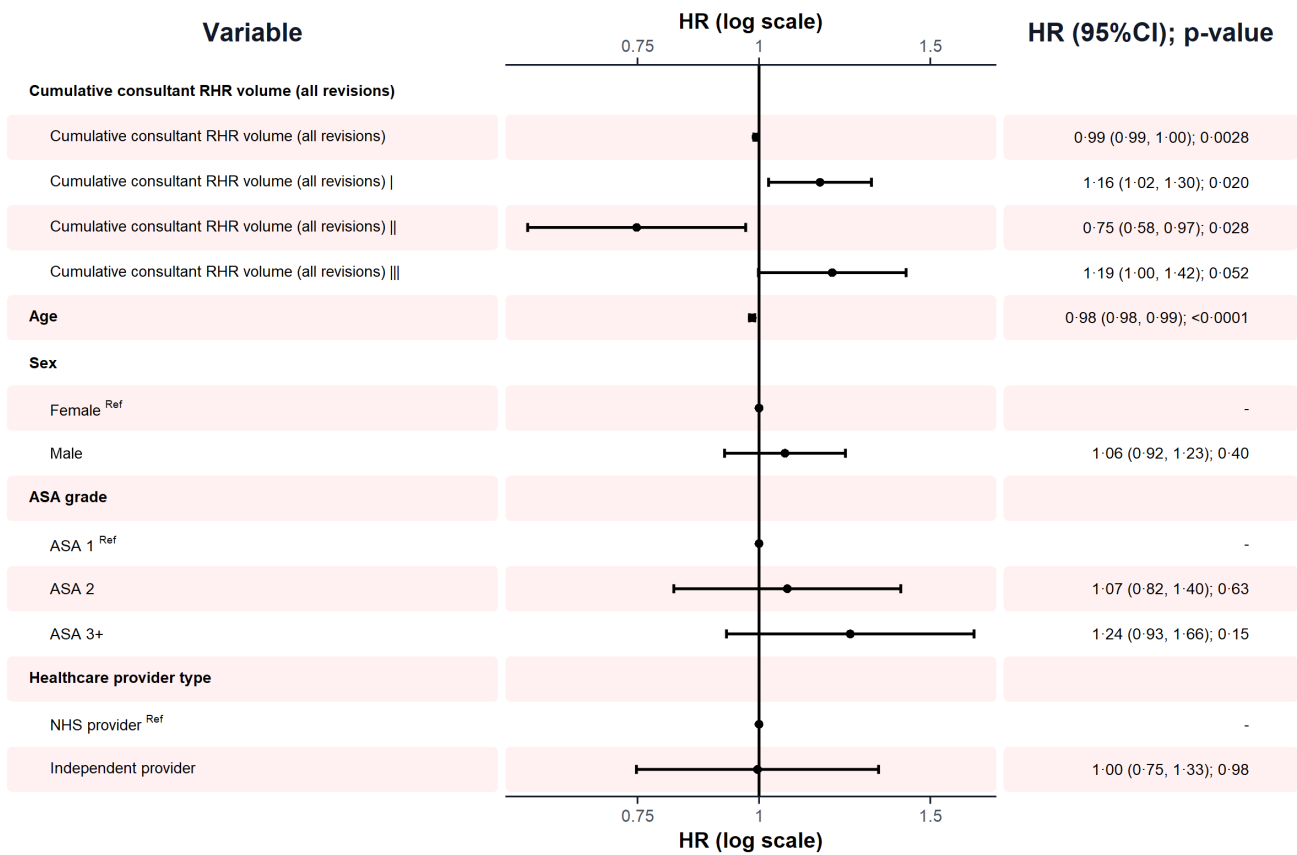
Variable	Cumulative consultant RHR volume (all revisions)					All cases
	0 to 23 n=1,303 (10.1%)	24 to 92 n=3,038 (23.4%)	93 to 240 n=4,307 (33.2%)	241 to 477 n=3,021 (23.3%)	478 to 1,151 n=1,292 (10.0%)	
Age [mean (SD)]	72.9 (11.0)	72.6 (10.9)	72.3 (11.2)	72.9 (11.1)	72.6 (10.6)	72.6 (11.0)
Sex [n (%)]						
Female	692 (53.1)	1,633 (53.8)	2,315 (53.7)	1,706 (56.5)	717 (55.5)	7,063 (54.5)
Male	611 (46.9)	1,405 (46.2)	1,992 (46.3)	1,315 (43.5)	575 (44.5)	5,898 (45.5)
Body mass index [mean (SD)]	29.2 (5.2)	29.1 (5.4)	28.8 (5.3)	28.6 (5.0)	28.5 (5.2)	28.8 (5.2)
ASA grade [n (%)]						
ASA 1	88 (6.8)	185 (6.1)	327 (7.6)	199 (6.6)	112 (8.7)	911 (7.0)
ASA 2	776 (59.6)	1,813 (59.7)	2,538 (58.9)	1,851 (61.3)	830 (64.2)	7,808 (60.2)
ASA 3+	439 (33.7)	1,040 (34.2)	1,442 (33.5)	971 (32.1)	350 (27.1)	4,242 (32.7)
Practice setting [n (%)]						
NHS provider	1,234 (94.7)	2,904 (95.6)	4,062 (94.3)	2,799 (92.7)	1,024 (79.3)	12,023 (92.8)
Independent provider	69 (5.3)	134 (4.4)	245 (5.7)	222 (7.3)	268 (20.7)	938 (7.2)
Components replaced at revision [n (%)]						
Acetabular & femoral	610 (46.8)	1,603 (52.8)	2,316 (53.8)	1,722 (57.0)	665 (51.5)	6,916 (53.4)
Acetabular only	438 (33.6)	895 (29.5)	1,316 (30.6)	882 (29.2)	444 (34.4)	3,975 (30.7)
Femoral only	216 (16.6)	476 (15.7)	580 (13.5)	372 (12.3)	162 (12.5)	1,806 (13.9)
Head and/or liner only	36 (2.8)	59 (1.9)	91 (2.1)	43 (1.4)	21 (1.6)	250 (1.9)
No components replaced	3 (0.23)	5 (0.16)	4 (0.09)	2 (0.07)	0 (0)	14 (0.11)
Bone graft use at revision [n (%)]						
Acetabular bone grafting	301 (23.1)	708 (23.3)	1,143 (26.5)	733 (24.3)	326 (25.2)	3,211 (24.8)
Femoral bone grafting	31 (2.4)	69 (2.3)	103 (2.4)	68 (2.3)	25 (1.9)	296 (2.3)
Acetabular & Femoral bone grafting	33 (2.5)	83 (2.7)	143 (3.3)	116 (3.8)	33 (2.6)	408 (3.1)
No bone grafting	938 (72.0)	2,178 (71.7)	2,918 (67.8)	2,104 (69.6)	908 (70.3)	9,046 (69.8)
Lead & assistant surgeon grade [n (%)]						
Consultant assisted by non-consultant	1,169 (89.7)	2,756 (90.7)	3,835 (89.0)	2,668 (88.3)	1,102 (85.3)	11,530 (89.0)
Consultant assisted by consultant	73 (5.6)	141 (4.6)	174 (4.0)	55 (1.8)	12 (0.93)	455 (3.5)
Non-consultant assisted by consultant	35 (2.7)	103 (3.4)	244 (5.7)	240 (7.9)	107 (8.3)	729 (5.6)
Non-consultant assisted by non-consultant	26 (2.0)	38 (1.3)	54 (1.3)	58 (1.9)	71 (5.5)	247 (1.9)
Intra-operative complication [n (%)]						
No intra-operative complication recorded	1,249 (95.9)	2,888 (95.1)	4,176 (97.0)	2,926 (96.9)	1,280 (99.1)	12,519 (96.6)
Intra-operative complication recorded	54 (4.1)	150 (4.9)	131 (3.0)	95 (3.1)	12 (0.93)	442 (3.4)

Cases were grouped approximately into thirds (tertiles) of cumulative consultant RHR volume (all revisions). To compare case characteristics at the extremes of surgical volume, the lower and upper tertiles were further subdivided by identifying cases representing the bottom and top 10% of the distribution (unless the skewness precluded this). RHR = revision hip replacement; ASA = American Society of Anaesthesiologists; NHS = National Health Service.



**Figure d.** Adjusted and unadjusted marginal association of change in cumulative consultant RHR volume (all revisions) with risk of all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



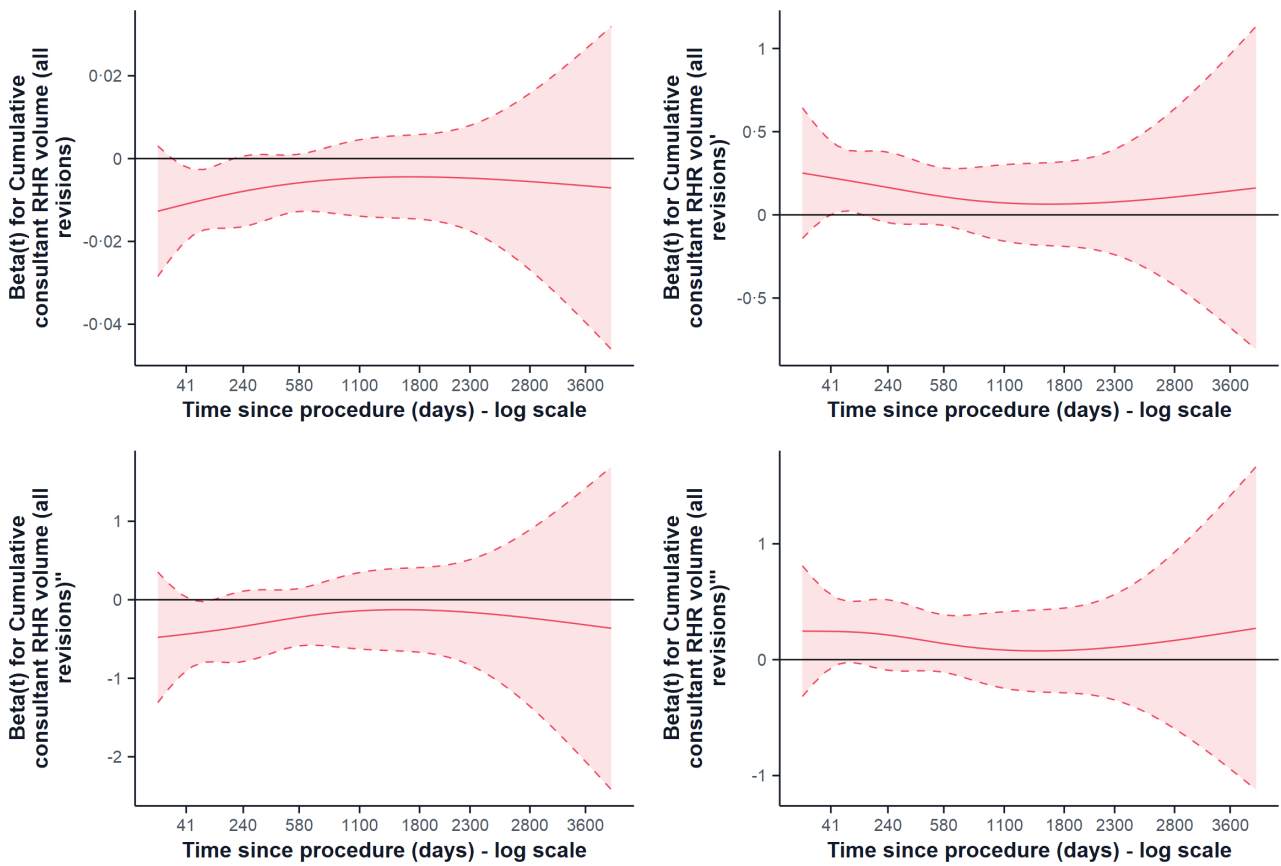


**Figure e.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S4. Number of observations = 12,961. Number of events = 756. R squared = 0.00347. Akaike information criterion (AIC) = 13,618.

**Table v. Tests of proportional hazards assumptions for cumulative consultant RHR volume (all revisions) restricted cubic spline term**

Parameter	p
Cumulative consultant RHR volume (all revisions)	0.537
Cumulative consultant RHR volume (all revisions)'	0.199
Cumulative consultant RHR volume (all revisions)''	0.170
Cumulative consultant RHR volume (all revisions)'''	0.134

Table showing the results of formal testing of proportional hazards for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model.



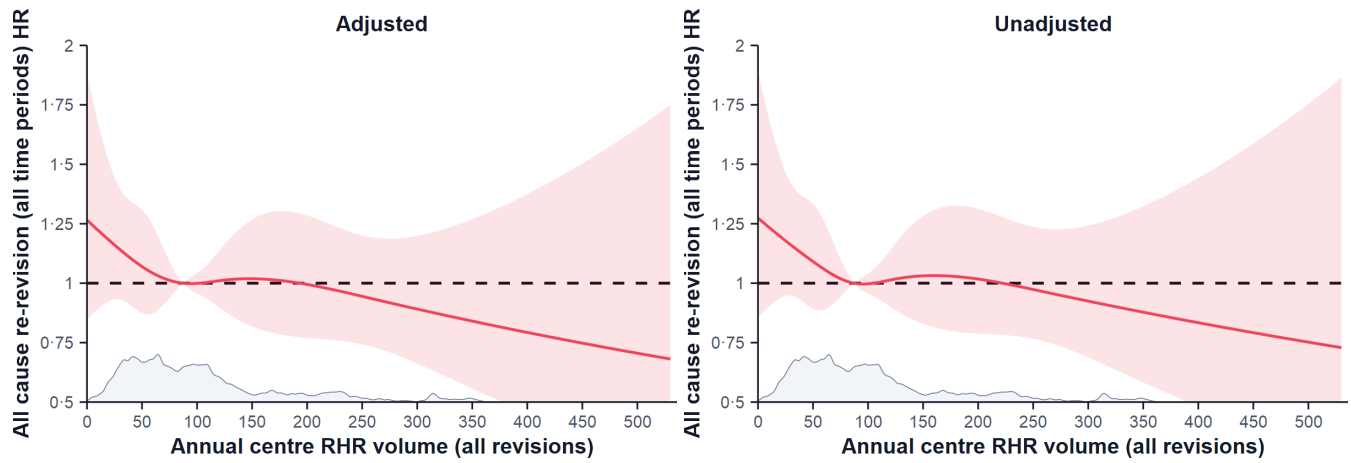
**Figure f.** Plot of the smoothed scaled Schoenfeld residuals for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model. Shaded area indicates the 95% confidence interval.

Annual centre RHR volume (all revisions)

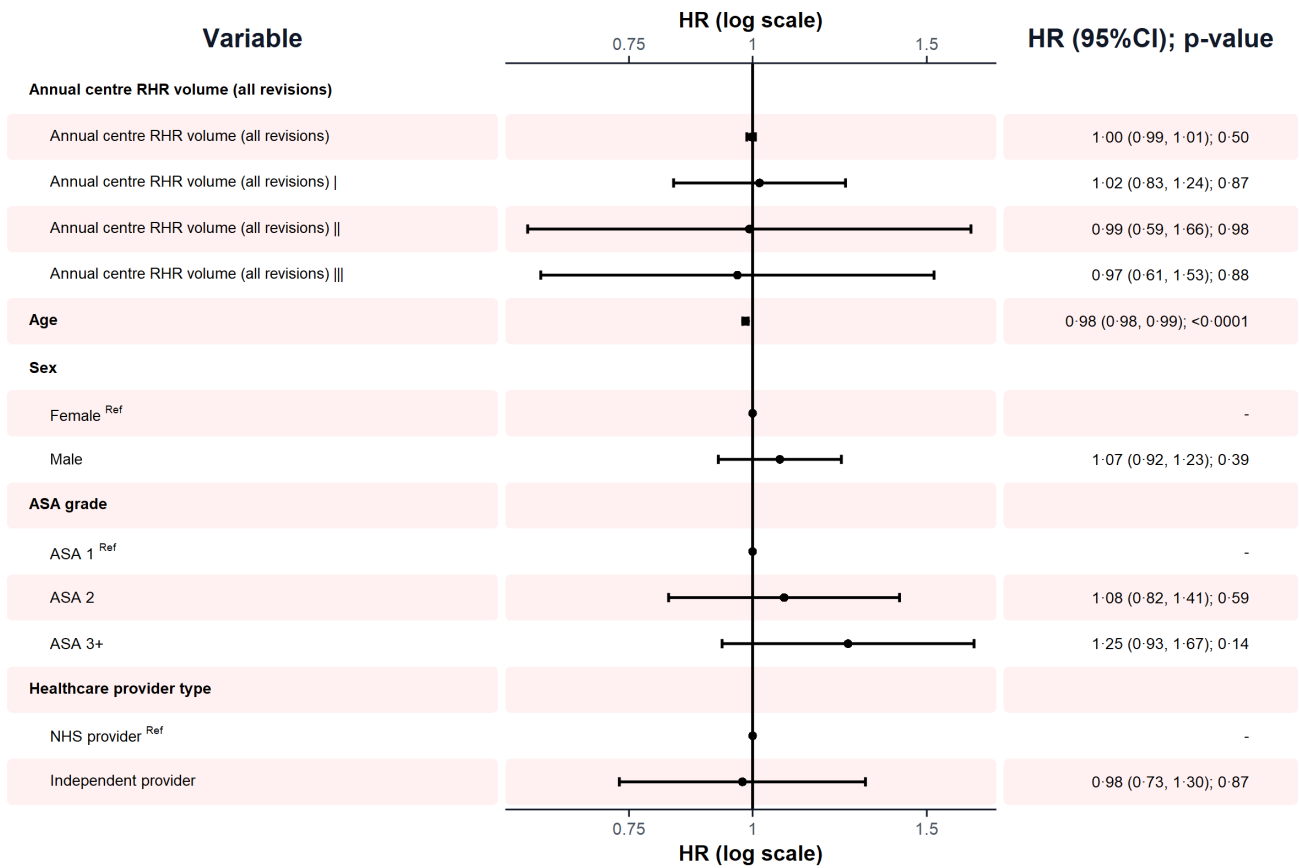
Table vi. Characteristics of study cohort by annual centre RHR volume (all revisions) group

Variable	Annual centre RHR volume (all revisions)					All cases
	0 to 32 n=1,311 (10.1%)	33 to 62 n=3,020 (23.3%)	63 to 111 n=4,311 (33.3%)	112 to 219 n=3,023 (23.3%)	220 to 530 n=1,296 (10.0%)	
<b>Age [mean (SD)]</b>	73.1 (10.5)	72.8 (11.0)	73.0 (10.8)	72.1 (11.4)	71.1 (11.6)	72.6 (11.0)
<b>Sex [n (%)]</b>						
Female	661 (50.4)	1,617 (53.5)	2,390 (55.4)	1,699 (56.2)	696 (53.7)	7,063 (54.5)
Male	650 (49.6)	1,403 (46.5)	1,921 (44.6)	1,324 (43.8)	600 (46.3)	5,898 (45.5)
<b>Body mass index [mean (SD)]</b>	29.0 (5.3)	28.9 (5.3)	28.8 (5.3)	28.6 (5.1)	28.5 (5.2)	28.8 (5.2)
<b>ASA grade [n (%)]</b>						
ASA 1	92 (7.0)	189 (6.3)	271 (6.3)	237 (7.8)	122 (9.4)	911 (7.0)
ASA 2	760 (58.0)	1,720 (57.0)	2,644 (61.3)	1,877 (62.1)	807 (62.3)	7,808 (60.2)
ASA 3+	459 (35.0)	1,111 (36.8)	1,396 (32.4)	909 (30.1)	367 (28.3)	4,242 (32.7)
<b>Practice setting [n (%)]</b>						
NHS provider	1,261 (96.2)	2,933 (97.1)	3,979 (92.3)	2,643 (87.4)	1,207 (93.1)	12,023 (92.8)
Independent provider	50 (3.8)	87 (2.9)	332 (7.7)	380 (12.6)	89 (6.9)	938 (7.2)
<b>Components replaced at revision [n (%)]</b>						
Acetabular & femoral	659 (50.3)	1,632 (54.0)	2,270 (52.7)	1,673 (55.3)	682 (52.6)	6,916 (53.4)
Acetabular only	414 (31.6)	897 (29.7)	1,376 (31.9)	874 (28.9)	414 (31.9)	3,975 (30.7)
Femoral only	199 (15.2)	422 (14.0)	582 (13.5)	422 (14.0)	181 (14.0)	1,806 (13.9)
Head and/or liner only	36 (2.7)	63 (2.1)	78 (1.8)	54 (1.8)	19 (1.5)	250 (1.9)
No components replaced	3 (0.23)	6 (0.20)	5 (0.12)	0 (0)	0 (0)	14 (0.11)
<b>Bone graft use at revision [n (%)]</b>						
Acetabular bone grafting	279 (21.3)	771 (25.5)	1,042 (24.2)	745 (24.6)	374 (28.9)	3,211 (24.8)
Femoral bone grafting	27 (2.1)	76 (2.5)	115 (2.7)	48 (1.6)	30 (2.3)	296 (2.3)
Acetabular & Femoral bone grafting	31 (2.4)	107 (3.5)	152 (3.5)	65 (2.2)	53 (4.1)	408 (3.1)
No bone grafting	974 (74.3)	2,066 (68.4)	3,002 (69.6)	2,165 (71.6)	839 (64.7)	9,046 (69.8)
<b>Lead &amp; assistant surgeon grade [n (%)]</b>						
Consultant assisted by non-consultant	1,211 (92.4)	2,774 (91.9)	3,981 (92.3)	2,476 (81.9)	1,088 (84.0)	11,530 (89.0)
Consultant assisted by consultant	68 (5.2)	161 (5.3)	131 (3.0)	72 (2.4)	23 (1.8)	455 (3.5)
Non-consultant assisted by consultant	16 (1.2)	54 (1.8)	138 (3.2)	369 (12.2)	152 (11.7)	729 (5.6)
Non-consultant assisted by non-consultant	16 (1.2)	31 (1.0)	61 (1.4)	106 (3.5)	33 (2.5)	247 (1.9)
<b>Intra-operative complication [n (%)]</b>						
No intra-operative complication recorded	1,254 (95.7)	2,871 (95.1)	4,177 (96.9)	2,936 (97.1)	1,281 (98.8)	12,519 (96.6)
Intra-operative complication recorded	57 (4.3)	149 (4.9)	134 (3.1)	87 (2.9)	15 (1.2)	442 (3.4)

Cases were grouped approximately into thirds (tertiles) of annual centre RHR volume (all revisions). To compare case characteristics at the extremes of surgical volume, the lower and upper tertiles were further subdivided by identifying cases representing the bottom and top 10% of the distribution (unless the skewness precluded this). RHR = revision hip replacement; ASA = American Society of Anaesthesiologists; NHS = National Health Service.



**Figure g.** Adjusted and unadjusted marginal association of change in annual centre RHR volume (all revisions) with risk of all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

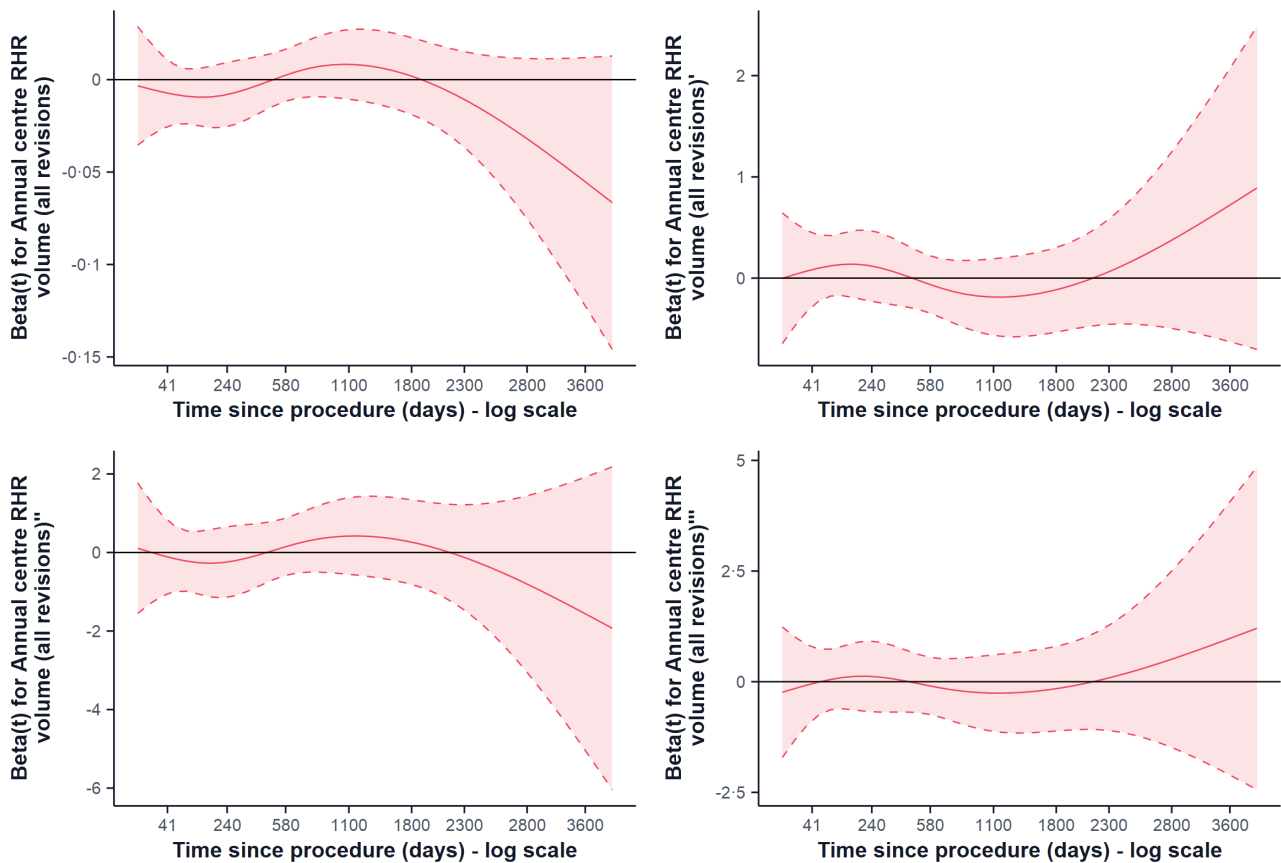


**Figure h.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S7. Number of observations = 12,961. Number of events = 756. R squared = 0.00233. Akaike information criterion (AIC) = 13,633.

**Table vii. Tests of proportional hazards assumptions for annual centre RHR volume (all revisions) restricted cubic spline term**

Parameter	p
Annual centre RHR volume (all revisions)	0.601
Annual centre RHR volume (all revisions)'	0.661
Annual centre RHR volume (all revisions)''	0.550
Annual centre RHR volume (all revisions)'''	0.441

Table showing the results of formal testing of proportional hazards for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model.



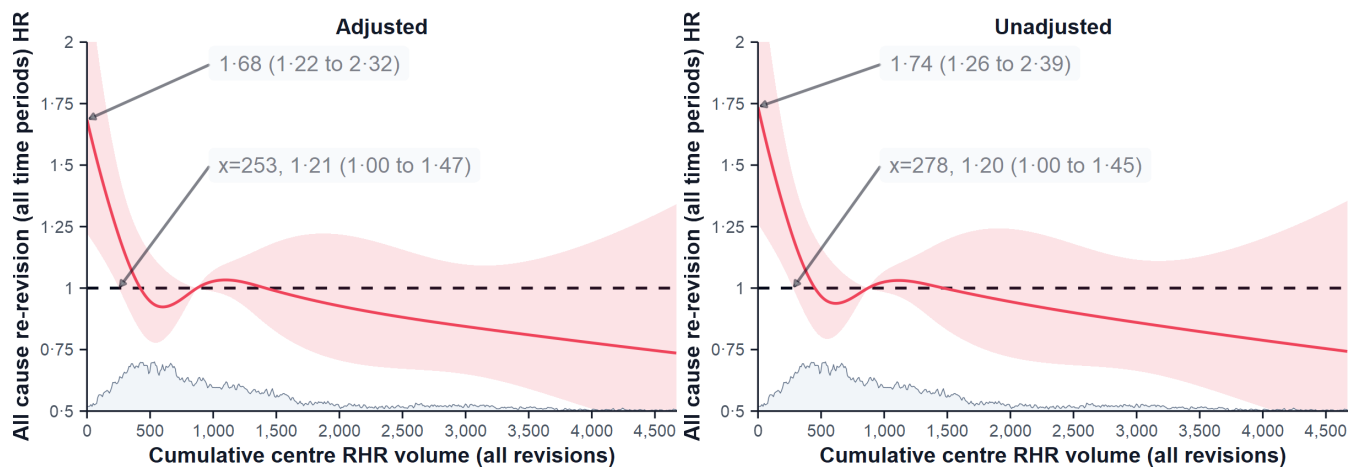
**Figure i.** Plot of the smoothed scaled Schoenfeld residuals for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model. Shaded area indicates the 95% confidence interval.

Cumulative centre RHR volume (all revisions)

Table viii. Characteristics of study cohort by cumulative centre RHR volume (all revisions) group

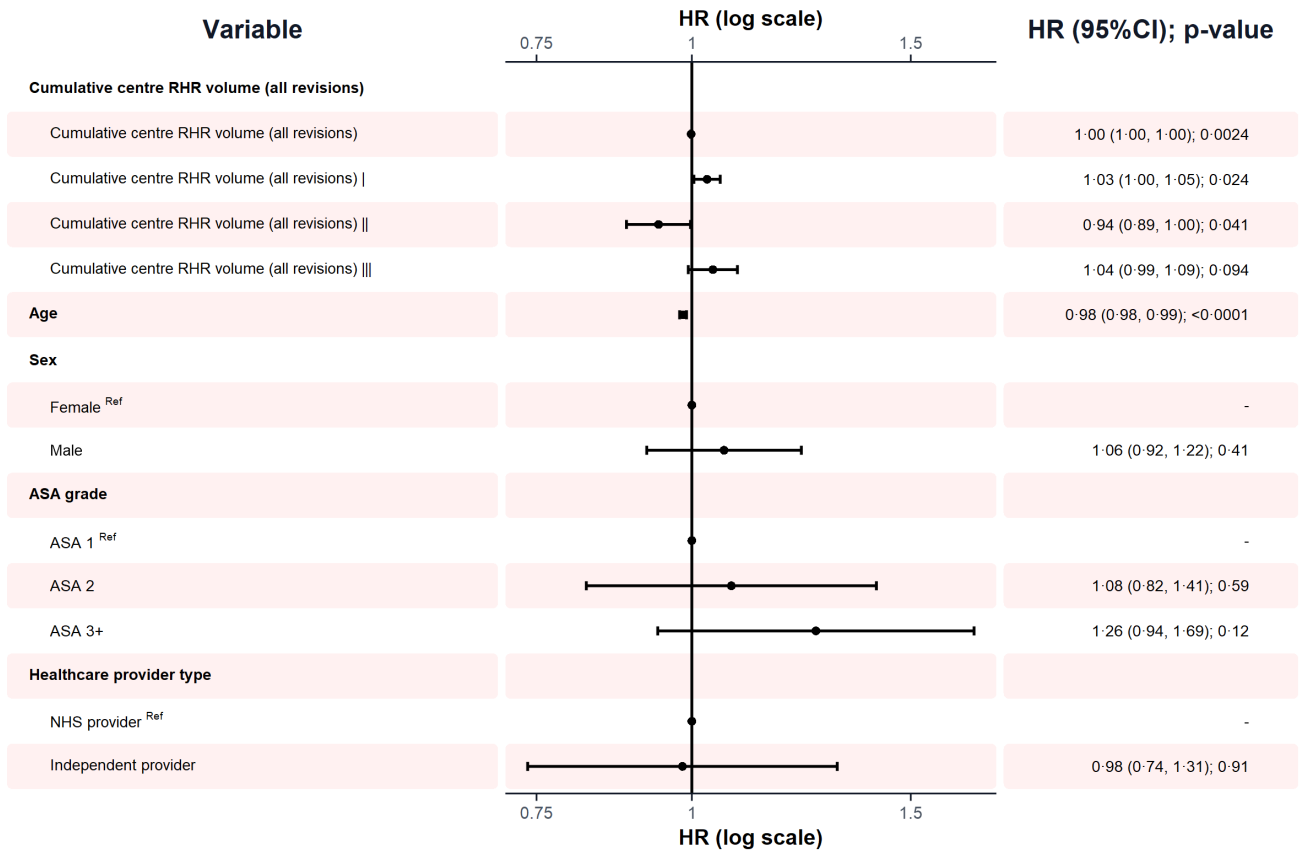
Variable	Cumulative centre RHR volume (all revisions)					All cases
	0 to 298 n=1,307 (10.1%)	299 to 603 n=3,024 (23.3%)	604 to 1,241 n=4,316 (33.3%)	1,242 to 2,706 n=3,018 (23.3%)	2,708 to 4,669 n=1,296 (10.0%)	
Age [mean (SD)]	71.5 (11.2)	72.5 (10.8)	73.2 (10.9)	72.6 (11.4)	72.0 (11.0)	72.6 (11.0)
Sex [n (%)]						
Female	676 (51.7)	1,614 (53.4)	2,410 (55.8)	1,675 (55.5)	688 (53.1)	7,063 (54.5)
Male	631 (48.3)	1,410 (46.6)	1,906 (44.2)	1,343 (44.5)	608 (46.9)	5,898 (45.5)
Body mass index [mean (SD)]	28.8 (5.4)	29.2 (5.4)	28.7 (5.2)	28.8 (5.2)	28.2 (5.1)	28.8 (5.2)
ASA grade [n (%)]						
ASA 1	110 (8.4)	213 (7.0)	268 (6.2)	214 (7.1)	106 (8.2)	911 (7.0)
ASA 2	808 (61.8)	1,773 (58.6)	2,614 (60.6)	1,796 (59.5)	817 (63.0)	7,808 (60.2)
ASA 3+	389 (29.8)	1,038 (34.3)	1,434 (33.2)	1,008 (33.4)	373 (28.8)	4,242 (32.7)
Practice setting [n (%)]						
NHS provider	1,235 (94.5)	2,933 (97.0)	4,020 (93.1)	2,765 (91.6)	1,070 (82.6)	12,023 (92.8)
Independent provider	72 (5.5)	91 (3.0)	296 (6.9)	253 (8.4)	226 (17.4)	938 (7.2)
Components replaced at revision [n (%)]						
Acetabular & femoral	560 (42.8)	1,587 (52.5)	2,377 (55.1)	1,706 (56.5)	686 (52.9)	6,916 (53.4)
Acetabular only	441 (33.7)	909 (30.1)	1,328 (30.8)	852 (28.2)	445 (34.3)	3,975 (30.7)
Femoral only	260 (19.9)	458 (15.1)	537 (12.4)	397 (13.2)	154 (11.9)	1,806 (13.9)
Head and/or liner only	42 (3.2)	65 (2.1)	69 (1.6)	63 (2.1)	11 (0.85)	250 (1.9)
No components replaced	4 (0.31)	5 (0.17)	5 (0.12)	0 (0)	0 (0)	14 (0.11)
Bone graft use at revision [n (%)]						
Acetabular bone grafting	221 (16.9)	717 (23.7)	1,124 (26.0)	755 (25.0)	394 (30.4)	3,211 (24.8)
Femoral bone grafting	26 (2.0)	96 (3.2)	92 (2.1)	52 (1.7)	30 (2.3)	296 (2.3)
Acetabular & Femoral bone grafting	27 (2.1)	104 (3.4)	160 (3.7)	69 (2.3)	48 (3.7)	408 (3.1)
No bone grafting	1,033 (79.0)	2,107 (69.7)	2,940 (68.1)	2,142 (71.0)	824 (63.6)	9,046 (69.8)
Lead & assistant surgeon grade [n (%)]						
Consultant assisted by non-consultant	1,197 (91.6)	2,760 (91.3)	4,008 (92.9)	2,464 (81.6)	1,101 (85.0)	11,530 (89.0)
Consultant assisted by consultant	71 (5.4)	160 (5.3)	140 (3.2)	58 (1.9)	26 (2.0)	455 (3.5)
Non-consultant assisted by consultant	21 (1.6)	67 (2.2)	118 (2.7)	380 (12.6)	143 (11.0)	729 (5.6)
Non-consultant assisted by non-consultant	18 (1.4)	37 (1.2)	50 (1.2)	116 (3.8)	26 (2.0)	247 (1.9)
Intra-operative complication [n (%)]						
No intra-operative complication recorded	1,223 (93.6)	2,907 (96.1)	4,178 (96.8)	2,942 (97.5)	1,269 (97.9)	12,519 (96.6)
Intra-operative complication recorded	84 (6.4)	117 (3.9)	138 (3.2)	76 (2.5)	27 (2.1)	442 (3.4)

Cases were grouped approximately into thirds (tertiles) of cumulative centre RHR volume (all revisions). To compare case characteristics at the extremes of surgical volume, the lower and upper tertiles were further subdivided by identifying cases representing the bottom and top 10% of the distribution (unless the skewness precluded this). RHR = revision hip replacement; ASA = American Society of Anaesthesiologists; NHS = National Health Service.



**Figure j.** Adjusted and unadjusted marginal association of change in cumulative centre RHR volume (all revisions) with risk of all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



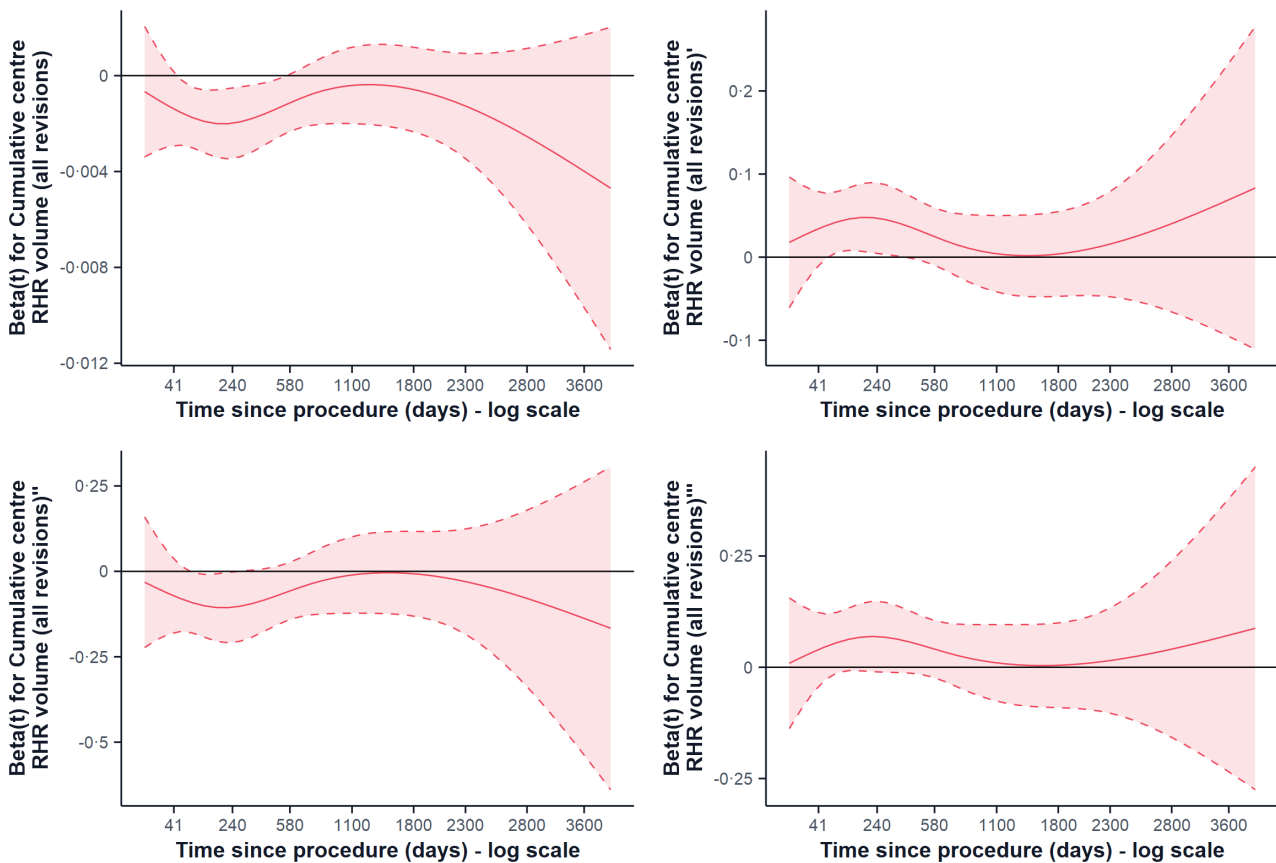


**Figure k.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision (all time periods) following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S10. Number of observations = 12,961. Number of events = 756. R squared = 0.00315. Akaike information criterion (AIC) = 13,623.

**Table ix. Tests of proportional hazards assumptions for cumulative centre RHR volume (all revisions) restricted cubic spline term**

Parameter	p
Cumulative centre RHR volume (all revisions)	0.553
Cumulative centre RHR volume (all revisions)'	0.429
Cumulative centre RHR volume (all revisions)''	0.325
Cumulative centre RHR volume (all revisions)'''	0.236

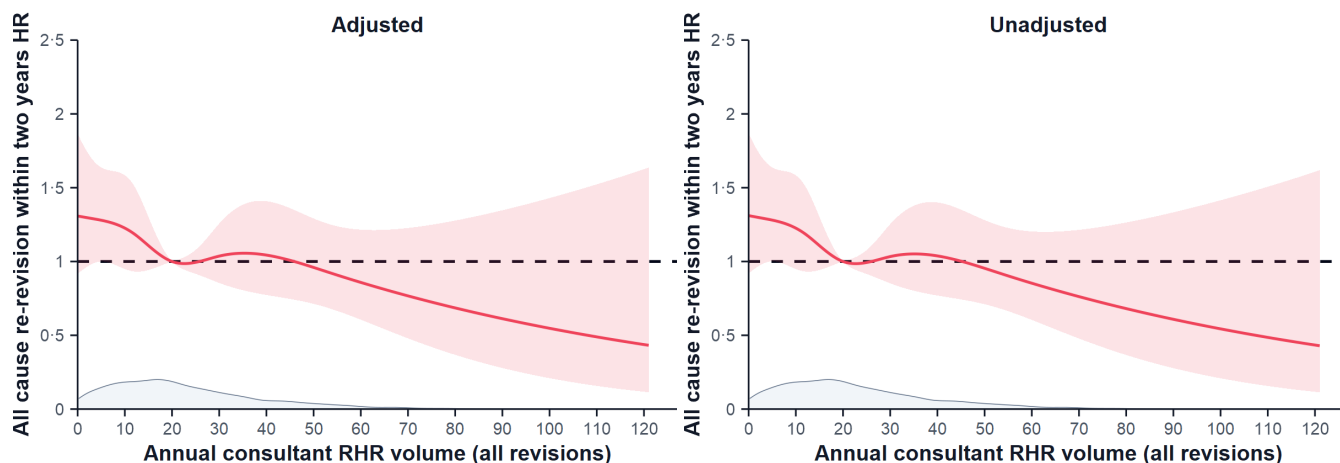
Table showing the results of formal testing of proportional hazards for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model.



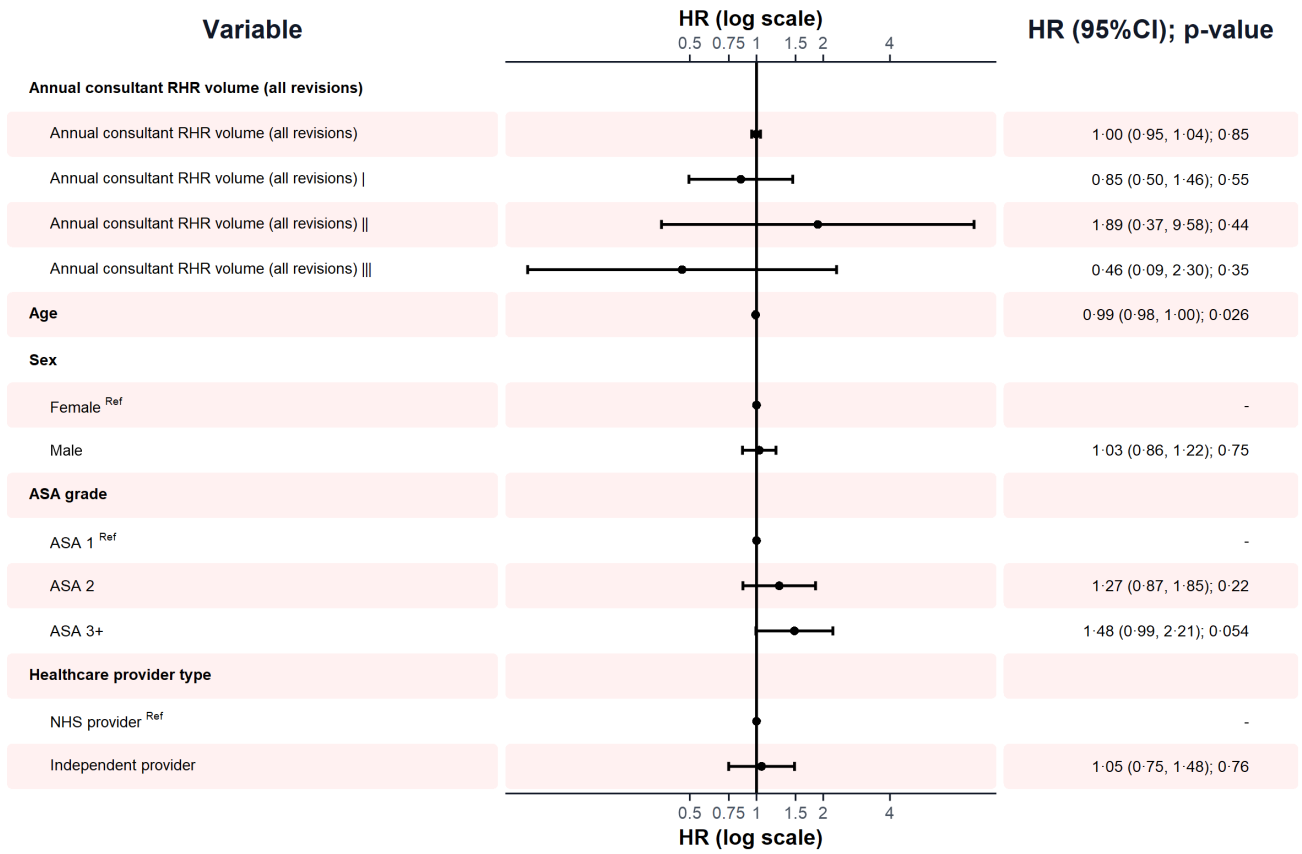
**Figure 1.** Plot of the smoothed scaled Schoenfeld residuals for each of the parameters of the restricted cubic spline term for surgical volume defined by the Cox model. Shaded area indicates the 95% confidence interval.

### Appendix 3: Association between surgical volume and all cause re-revision within two years

#### Annual consultant RHR volume (all revisions)

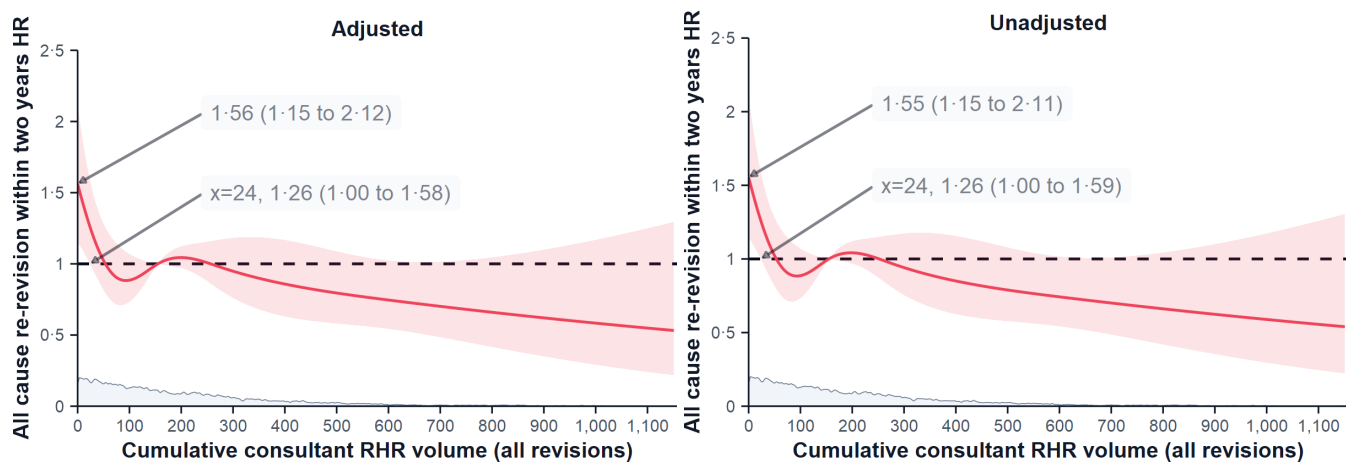


**Figure m.** Adjusted and unadjusted marginal association of change in annual consultant RHR volume (all revisions) with risk of all cause re-revision within two years following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

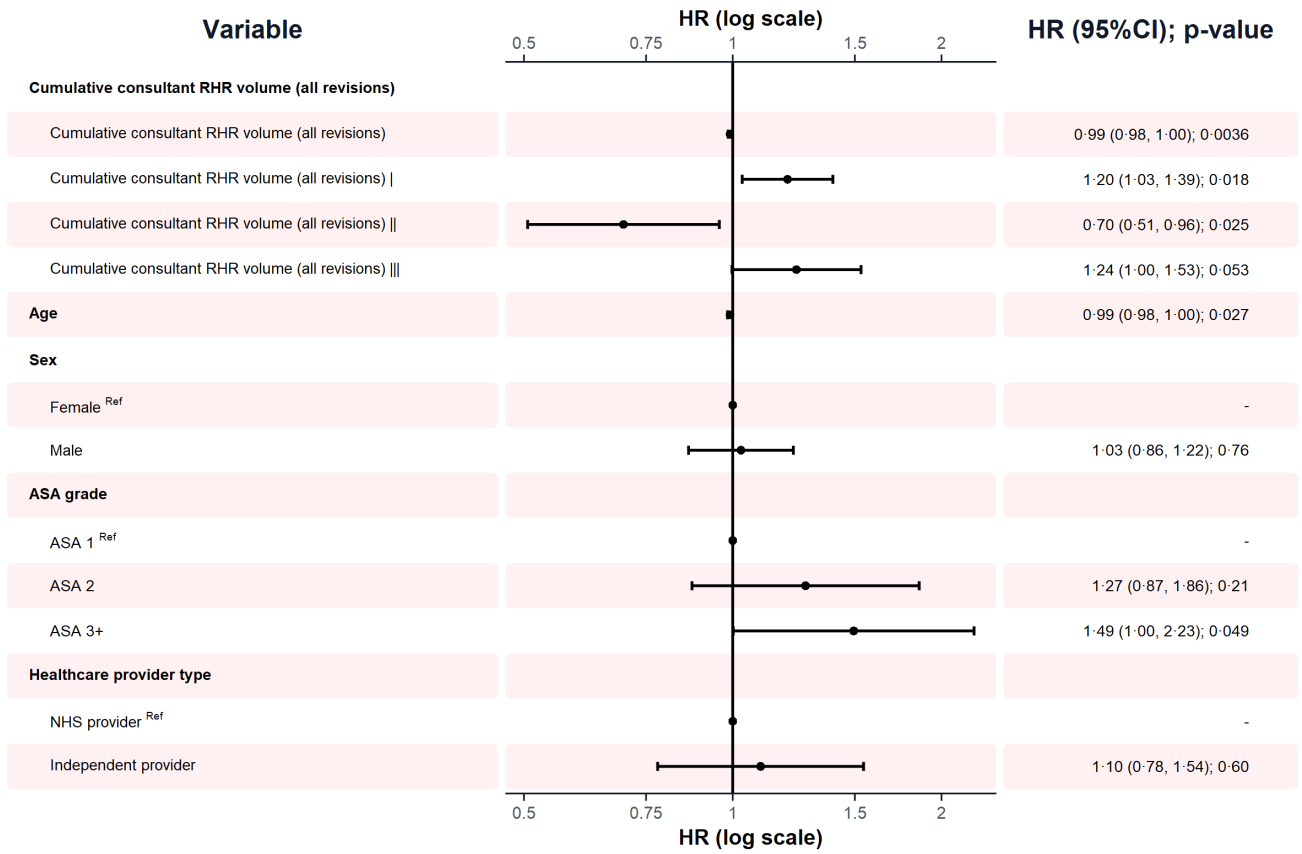


**Figure n.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision within two years following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S13. Number of observations = 12,961. Number of events = 513. R squared = 0.00117. Akaike information criterion (AIC) = 9,610.

**Cumulative consultant RHR volume (all revisions)**

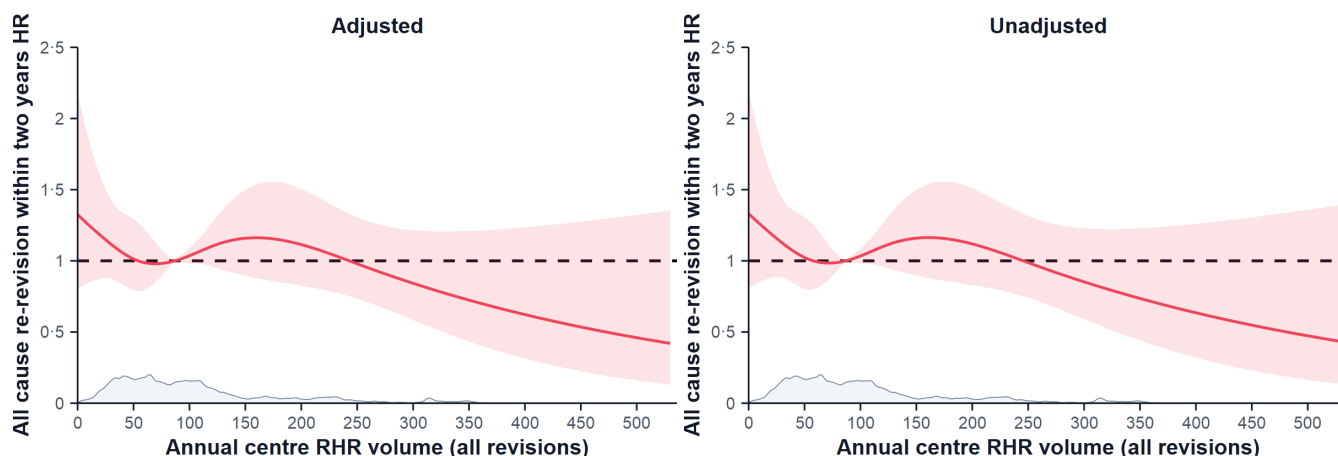


**Figure o.** Adjusted and unadjusted marginal association of change in cumulative consultant RHR volume (all revisions) with risk of all cause re-revision within two years following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

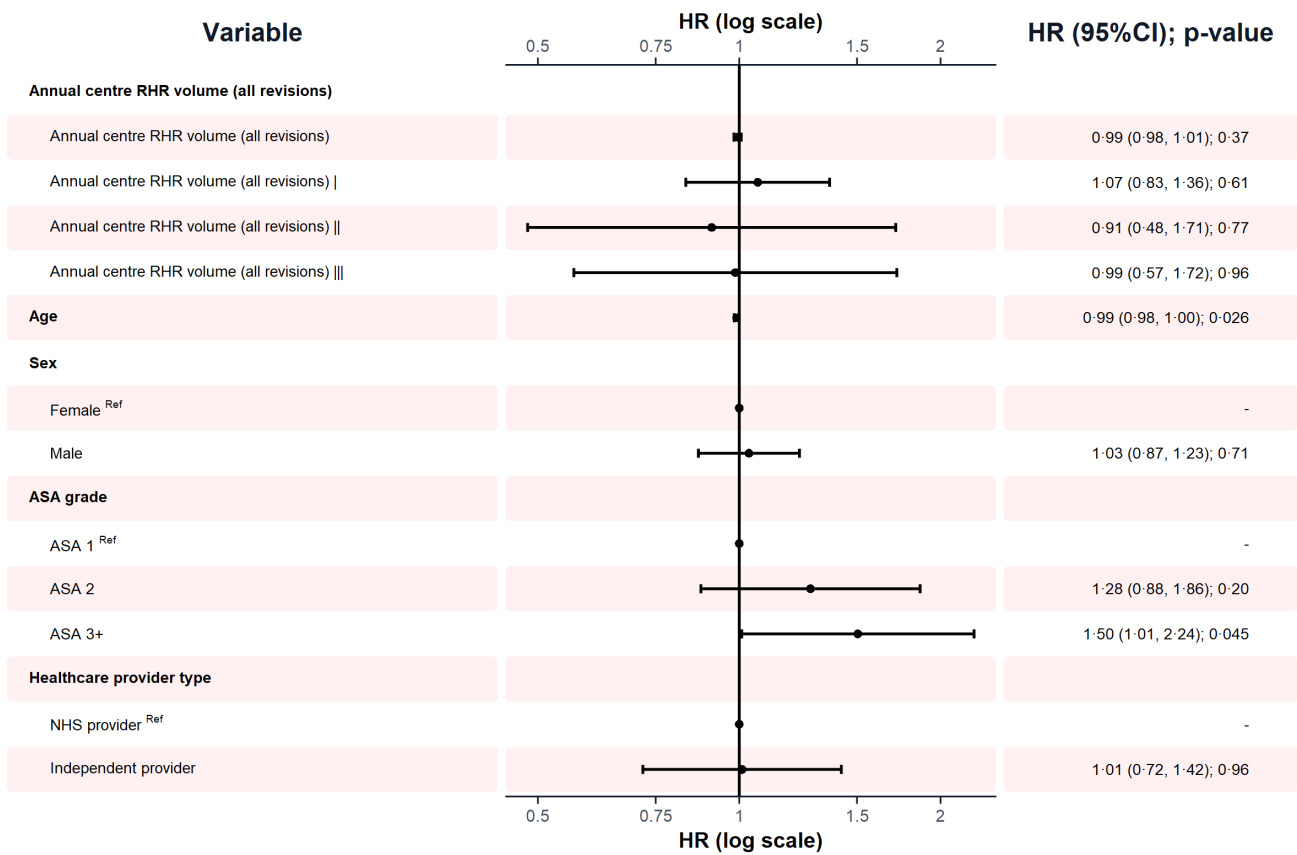


**Figure p.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision within two years following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S15. Number of observations = 12,961. Number of events = 513. R squared = 0.00186. Akaike information criterion (AIC) = 9,601.

**Annual centre RHR volume (all revisions)**



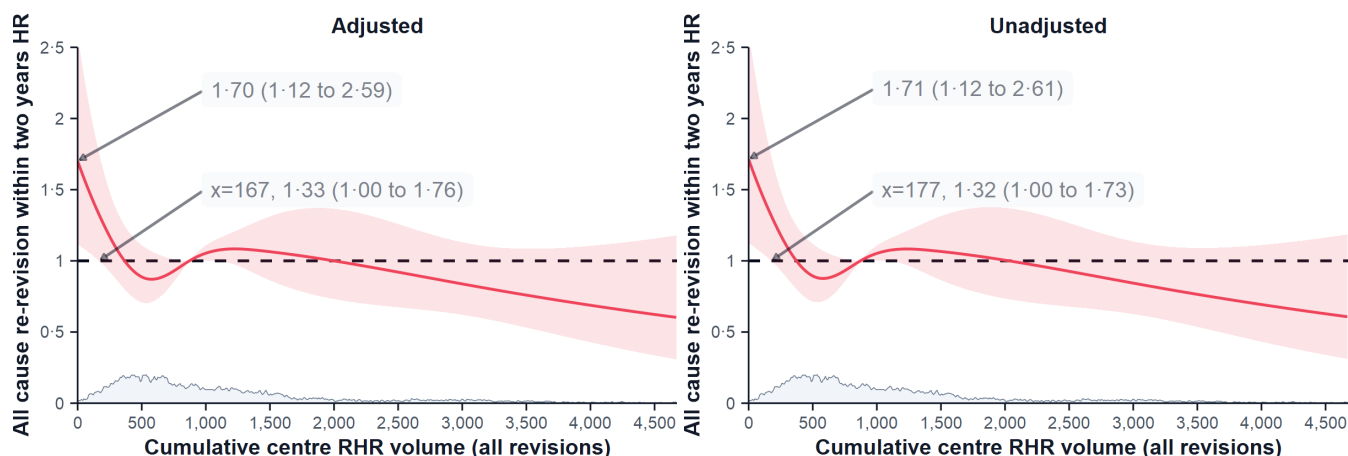
**Figure q.** Adjusted and unadjusted marginal association of change in annual centre RHR volume (all revisions) with risk of all cause re-revision within two years following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



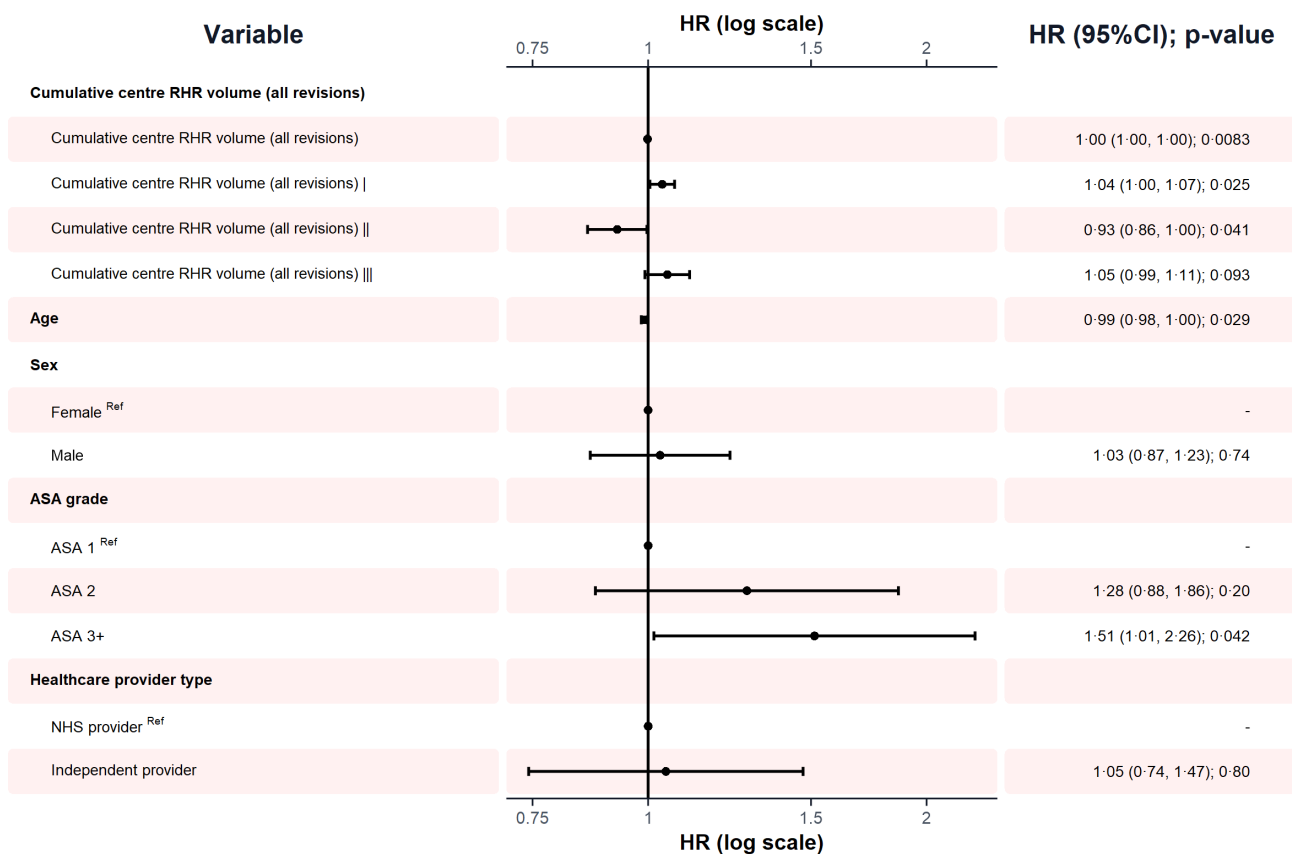
**Figure r.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision within two years following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S17. Number of observations = 12,961. Number of events = 513. R squared = 0.000883. Akaike information criterion (AIC) = 9,613.



**Cumulative centre RHR volume (all revisions)**



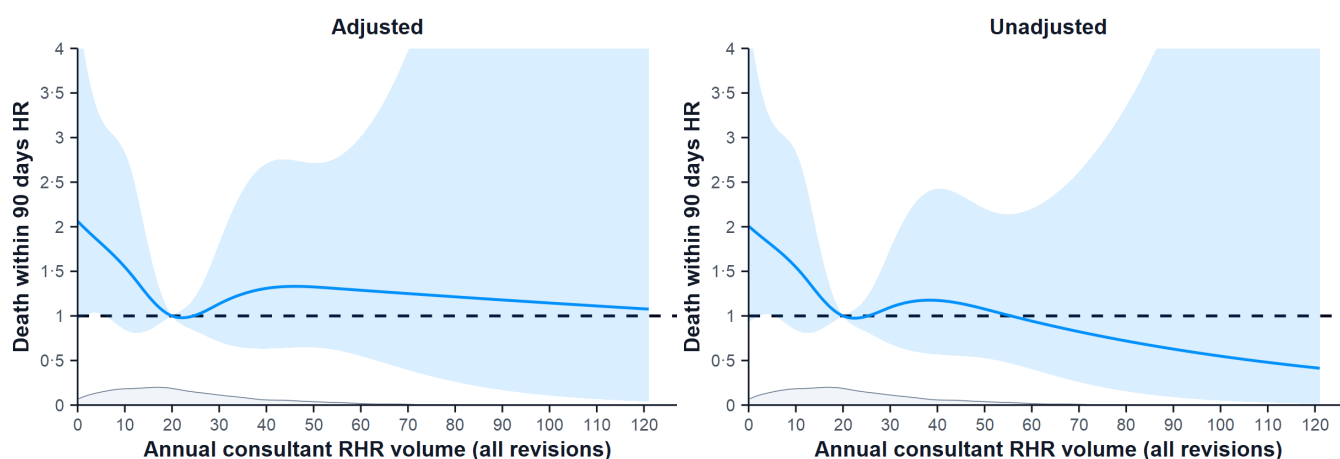
**Figure s.** Adjusted and unadjusted marginal association of change in cumulative centre RHR volume (all revisions) with risk of all cause re-revision within two years following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



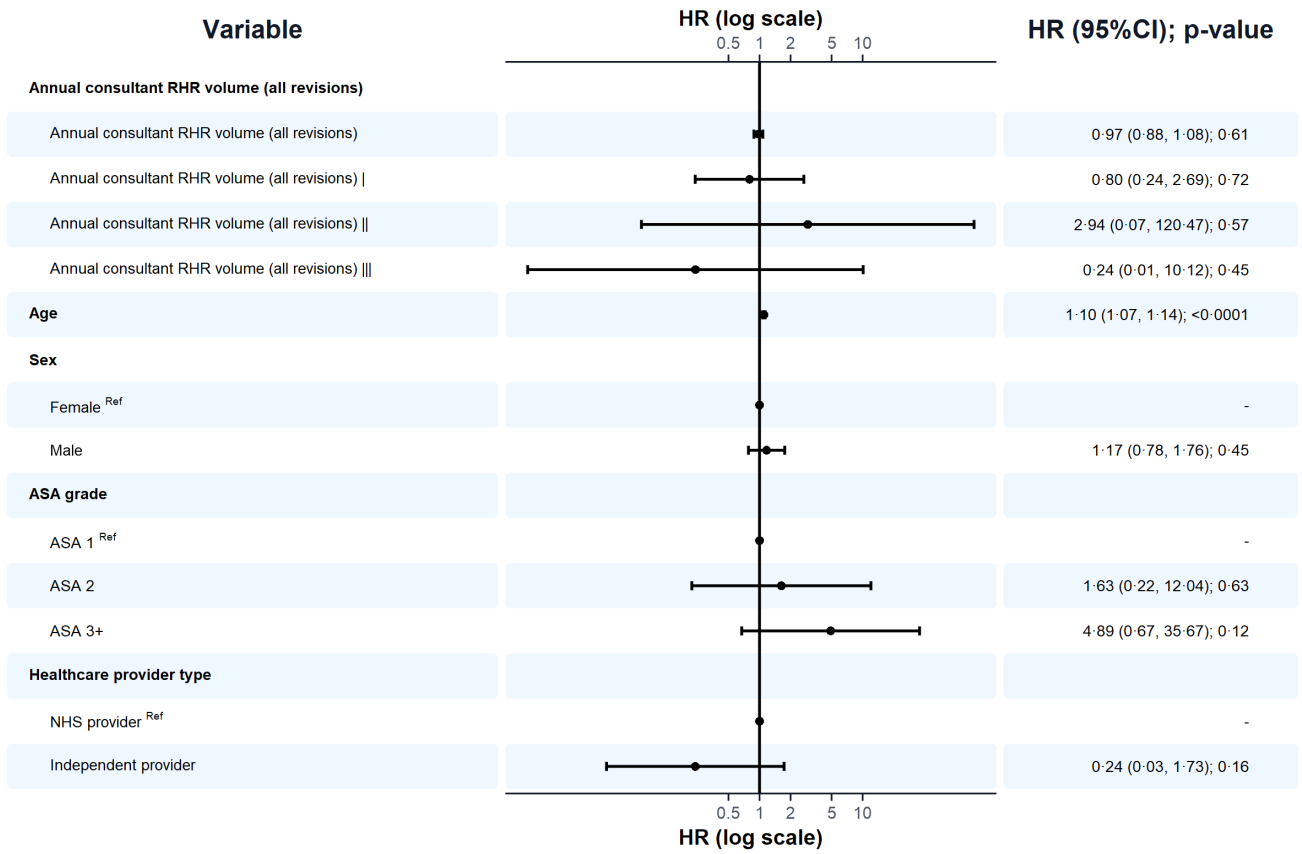
**Figure t.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting all cause re-revision within two years following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S19. Number of observations = 12,961. Number of events = 513. R squared = 0.00139. Akaike information criterion (AIC) = 9,607.

## Appendix 4: Association between surgical volume and death within 90 days

### Annual consultant RHR volume (all revisions)

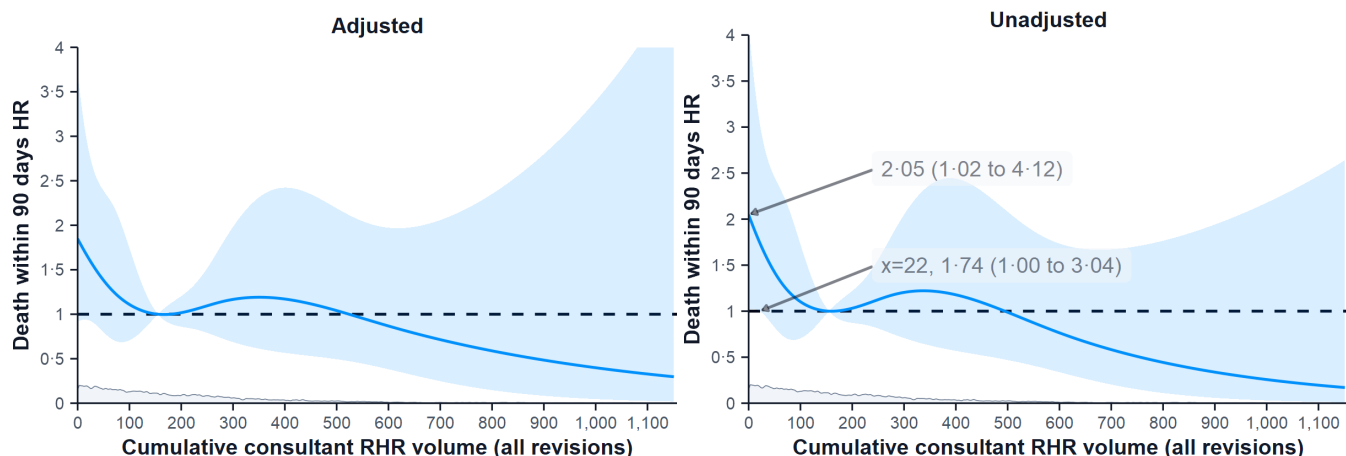


**Figure u.** Adjusted and unadjusted marginal association of change in annual consultant RHR volume (all revisions) with risk of death within 90 days following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

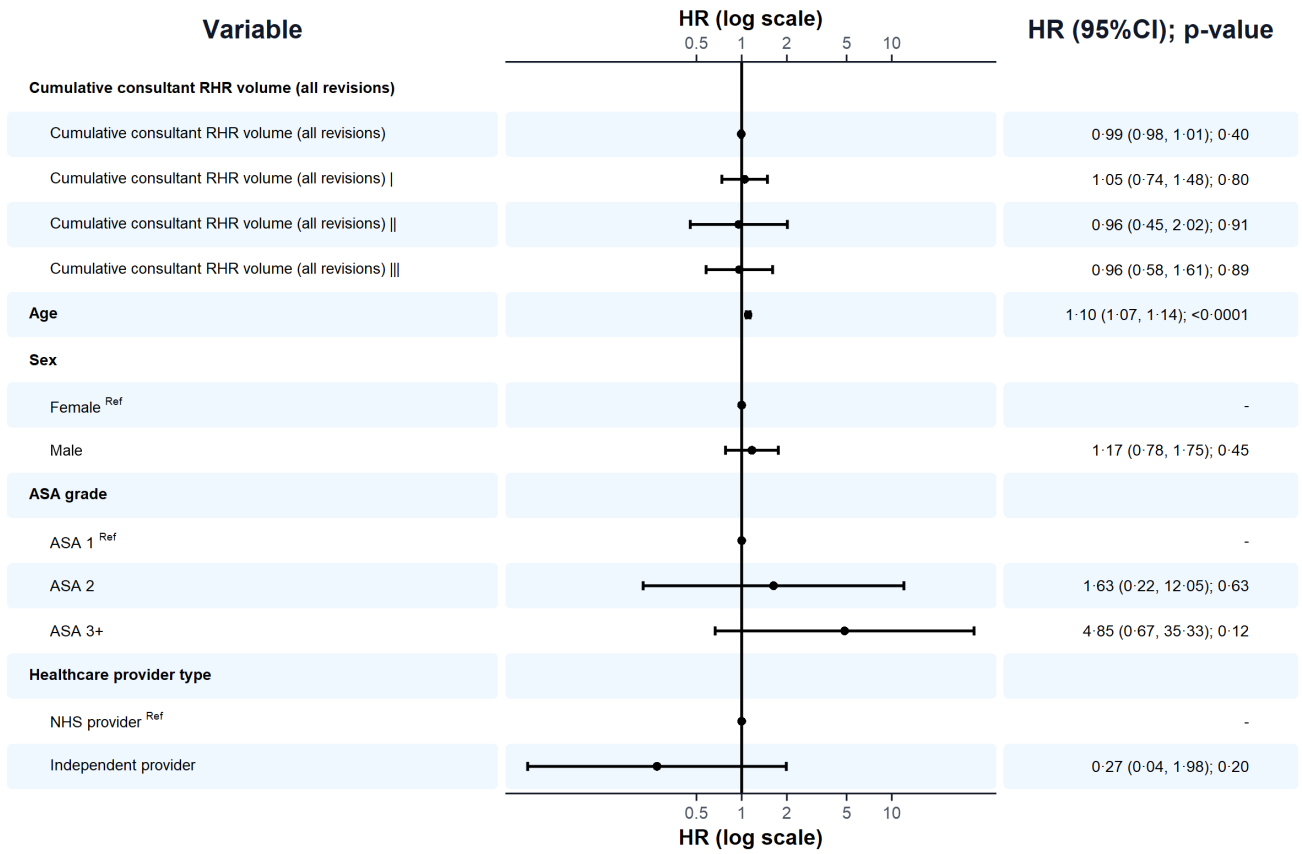


**Figure v.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting death within 90 days following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S21. Number of observations = 12,961. Number of events = 95. R squared = 0.00993. Akaike information criterion (AIC) = 1,687.

**Cumulative consultant RHR volume (all revisions)**

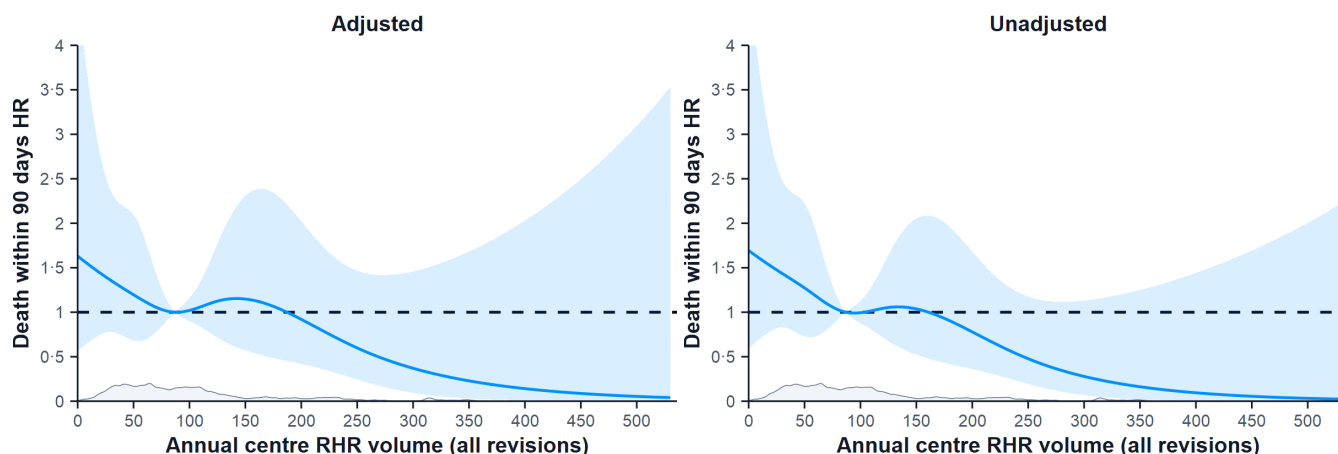


**Figure w.** Adjusted and unadjusted marginal association of change in cumulative consultant RHR volume (all revisions) with risk of death within 90 days following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative consultant RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.

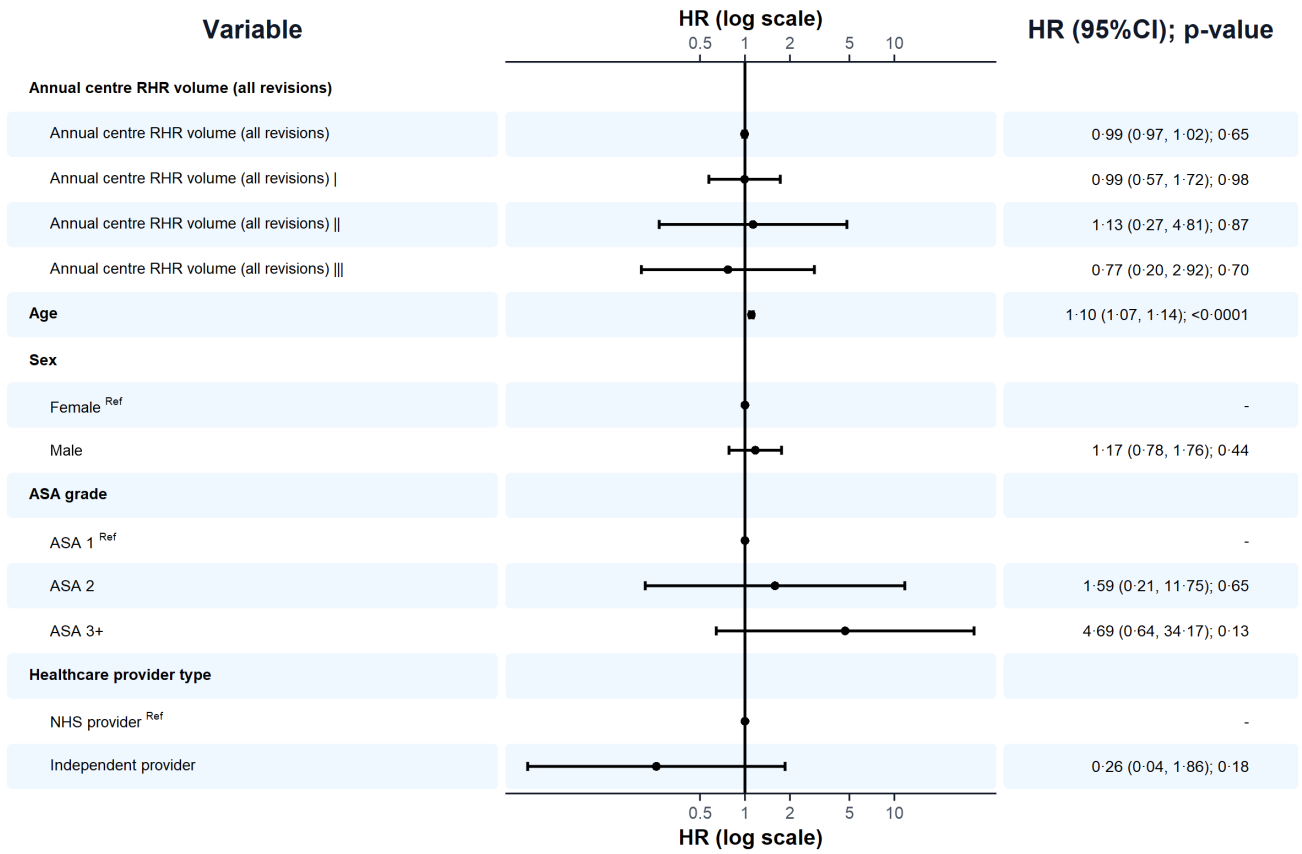


**Figure x.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting death within 90 days following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S23. Number of observations = 12,961. Number of events = 95. R squared = 0.00992. Akaike information criterion (AIC) = 1,687.

### Annual centre RHR volume (all revisions)



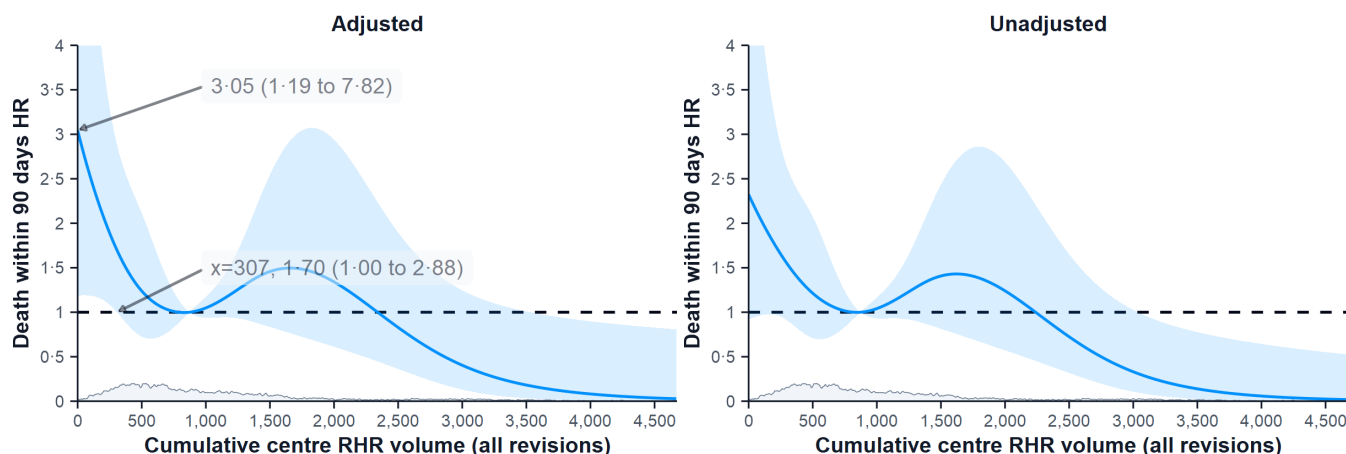
**Figure y.** Adjusted and unadjusted marginal association of change in annual centre RHR volume (all revisions) with risk of death within 90 days following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of annual centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



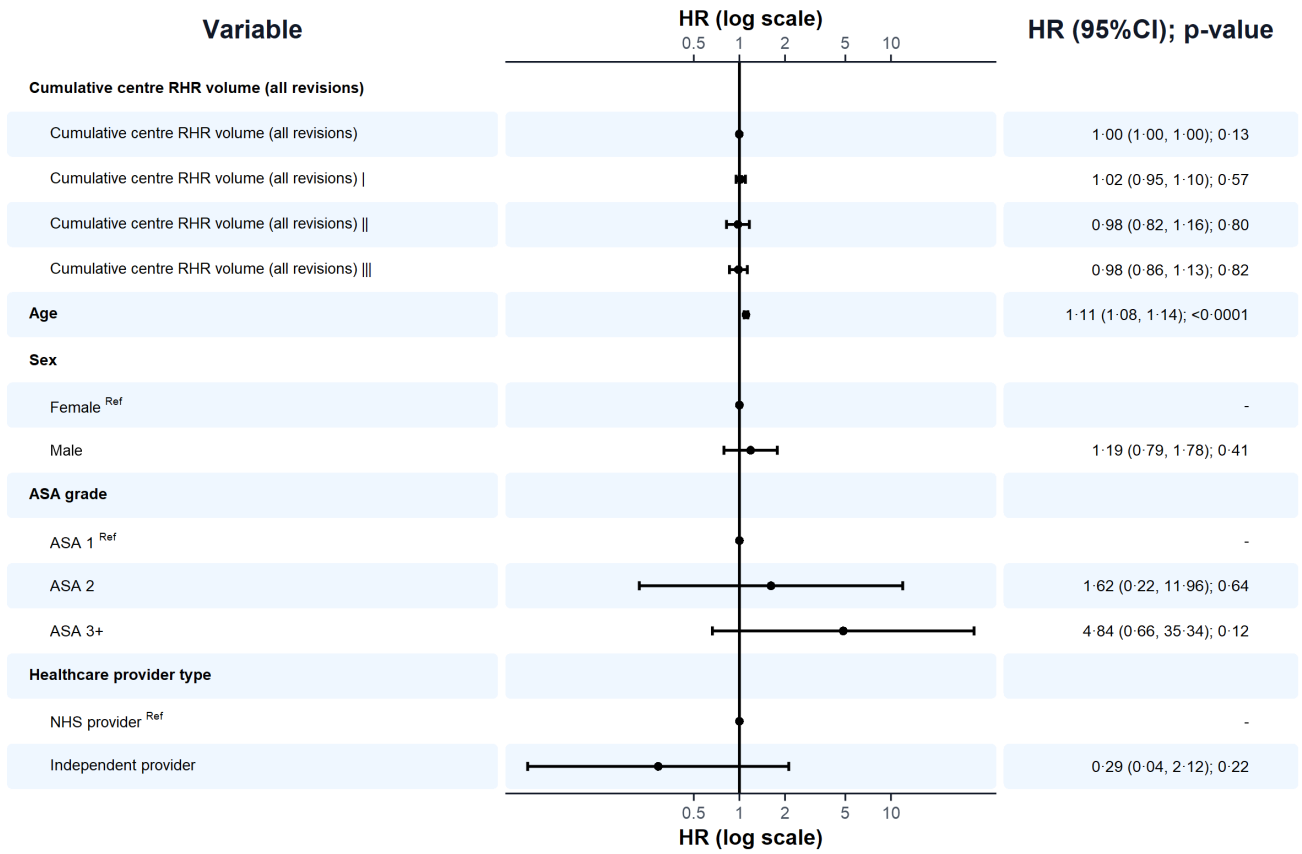
**Figure z.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting death within 90 days following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S25. Number of observations = 12,961. Number of events = 95. R squared = 0.00995. Akaike information criterion (AIC) = 1,687.



**Cumulative centre RHR volume (all revisions)**



**Figure aa.** Adjusted and unadjusted marginal association of change in cumulative centre RHR volume (all revisions) with risk of death within 90 days following 1st time RHR for aseptic loosening. Adjustment variables are presented in the next figure. Line and shaded area represent the HR and 95% confidence interval which converges where the spline is centered (referenced) at the median of cumulative centre RHR volume (all revisions). The grey rug-plot adjacent to the x-axis indicates the density of observations upon which the model is based. The annotation indicates (where relevant) the x-axis volume value corresponding to the intersection of the lower 95% confidence interval and a hazard ratio of one, highlighting the range of volume where risk is significantly elevated. RHR = revision hip replacement; HR = hazard ratio.



**Figure ab.** Hazard ratios (HR) and 95% confidence intervals (CI) for Cox proportional hazard model predicting death within 90 days following 1st time RHR for aseptic loosening. The raw spline terms from the model output are shown for completeness; these cannot be used to draw meaningful inferences about associations between surgical volume and outcome which instead must be derived from Figure S27. Number of observations = 12,961. Number of events = 95. R squared = 0.0106. Akaike information criterion (AIC) = 1,678.

