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Evaluation of factors driving cost variation for distal humerus open reduction internal fixation

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Background: Distal humerus fracture open reduction and internal fixation (ORIF) represents a substantial cost burden to the health care system. The purpose of this study was to describe surgical encounter cost variation for distal humerus ORIF, and to determine demographic-, injury-, and treatment-specific factors that influence cost.
Methods: We retrospectively identified adult patients (≥18 years) treated for isolated distal humerus fractures between July 2014 and July 2019 at a single tertiary academic referral center. For each case, surgical encounter total direct costs (SETDCs) were obtained via our institution's information technology value tools, which prospectively record granular direct cost data for every health care encounter. Costs were converted to 2019 dollars using the personal consumption expenditure indices for health and summarized with descriptive statistics. Univariate and multivariate linear regression models were used to identify factors influencing SETDC.
Results: Surgical costs varied widely for the 47 included patients, with a standard deviation (SD) of 33% and interquartile range of 76%-124% relative to the mean SETDC. Implant and facility costs were responsible for 46.2% and 32.6% of the SETDC, respectively. Implant costs also varied considerably, with an SD of 21% and range from 13%-36% relative to the mean SETDC. Multivariate analysis demonstrated that SETDC increased 24% ($P < .001$) on performing an olecranon osteotomy, and by 15% for each additional 1 hour of surgical time ($P < .001$). These findings were independent of age, sex, body mass index, open fracture, need for an additional small plate construct as a reduction aid, and fracture pattern (all insignificant in the multivariate analysis, with $P > .05$ for each factor).
Conclusion: Substantial variations in surgical encounter total direct costs for distal humerus ORIF exist, as do wide variations in associated implant costs that comprise nearly half of the entire surgical cost. Performing an olecranon osteotomy, and increased surgical time, significantly increased surgical costs. Although use of an olecranon osteotomy may not be a completely controllable factor as it is confounded by fracture severity and operative time, this may suggest that surgeons should try to use an olecranon osteotomy judiciously. Although complexity of the fracture pattern was statistically insignificant, it is confounded by the need for an olecranon osteotomy and increased surgical time and likely is a clinically relevant and nonmodifiable driver of surgical cost. These findings highlight opportunities to reduce cost variation, and potentially improve the value of care, for distal humerus ORIF patients.
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Distal humerus fractures are relatively common injuries in adults, accounting for approximately 2% of all fractures[2,36] and 30% of elbow fractures.[14] The incidence follows a bimodal age distribution, with peaks at a mean age of 37 years for men (typically resulting from high-energy trauma) and 60 years of age for women (most typically related to low-energy mechanisms in the setting of decreased bone mineral density).[14,34,36] The incidence of distal humerus fractures in the elderly is expected to increase, with a regression model projecting this value to triple by 2030.[23,34] Surgical management through open reduction and internal fixation

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(ORIF) is a common treatment method that may be performed for patients healthy enough to undergo surgery that demonstrate a fracture pattern and bone quality that is amenable to fixation.[24,41,46]

Although operative management of distal humerus fractures is generally accepted as the mainstay treatment of choice,[28] variation in the approach, technique, and instrumentation exists. This is, in part, due to differences in the complexity of the fracture pattern,[3] but also relates to surgeon preference and practice patterns. Additionally, the risk-benefit profile of some of these variations in treatment decision making, such as whether to perform ulnar nerve transposition or olecranon osteotomy, are disputed in the literature but may influence surgical cost.[9,30,37,39,40,47,51]

Although numerous clinical studies have evaluated the different treatment options available and their outcomes for distal humerus fractures,[14,24,28,41,46] less is known regarding the financial aspects of operative treatment of these injuries. With a wide variation in treatment options, and large projected increase in the incidence of distal humerus fractures in the near future, it is imperative to evaluate which specific modifiable and nonmodifiable factors lead to increased surgical costs for these injuries. Although cost differences between ORIF and total elbow arthroplasty have previously been studied,[13,50] specific patient and operative factors that drive variation in the surgical encounter total direct cost (SETDC) for distal humerus ORIF remain less clear. Highlighting the modifiable factors that drive cost variation for distal humerus ORIF provides an opportunity for potential cost savings.[50]

The purpose of this study was to describe the cost variation associated with distal humerus ORIF surgery and to investigate which demographic-, injury-, and treatment-specific factors impact the SETDC for distal humerus ORIF.

Materials and methods

This was a retrospective cohort cost study. All adult patients (age ≥18 years) undergoing surgical management of isolated distal humerus fractures between July 2014 and July 2019 at a single tertiary academic institution were identified. Patients were identified by a CPT code (24545, 24546, 24575, 24579, 24586) query of our institution's electronic data warehouse. Patients were excluded if they were younger than 18 years, had isolated capitellar shear or trochlear fractures, and if they had any additional simultaneous procedure in conjunction with distal humerus ORIF. Surgeries were performed by orthopedic surgeons with additional fellowship training in hand, shoulder and elbow, or trauma surgery. Demographic data, including age, body mass index, insurance, and race, were automatically pulled from the electronic data warehouse. Chart review of operative reports was performed to identify variations in the treatment of distal humerus fractures. Variables collected included number of plates used for distal humerus fixation (including use of small plate constructs as a reduction aid), fixation construct type (dual plating in a 90°-90° or 180° configuration), number of nonlocking and locking screws used, performance of olecranon osteotomy or ulnar nerve decompression and transposition, and the use of bone graft. Review of pre-, intra-, and postoperative radiographs was performed to corroborate the number of screws and plates used, and to classify the fracture pattern. Fracture pattern was defined as extra-articular, intra-articular simple, and intra-articular complex. A fracture was defined as extra-articular if it was an AO type A fracture, intra-articular simple if it was an AO type B or C1 fracture, and intra-articular complex if it was an AO type C2 or C3 fracture.[30]

In an effort to collect granular cost data for a wide spectrum of health care encounters, the Value Driven Outcomes (VDO) tool was previously developed at our institution.[25] The VDO tool encompasses an item-level database as well as information technology tools allowing for prospectively collected cost data to be linked to specific patient visits, including surgical encounters. Subcategories of the cost data include implant, supply, facility, operating room (OR), and postanesthesia care unit (PACU) use, pharmacy, imaging, and laboratory costs. Within the VDO tool, the costs of laboratory tests, pharmacy, and imaging are associated with the hospital stay as a whole, whereas OR and PACU use, implant, and supply costs can be linked to the specific surgical encounter. Given the inpatient status of the majority of our patients, the SETDC was composed of only OR and PACU use, supply, implant, and imaging costs. Previous literature using this tool in orthopedics has demonstrated that pharmacy, laboratory, and imaging costs comprise a relatively small portion (<5%) of the SETDC and therefore contribute minimally to surgical cost variation.[19,20,22] Therefore, we chose to omit these categories rather than exclude all inpatient surgeries. Additionally, professional payments including those to the surgeon and anesthesiologist, and indirect costs such as facility or equipment depreciation, are not included. Supplementary Appendix S1 provides a breakdown of each component included in the SETDC through the VDO. Although raw cost data was used for all analyses, all costs were reported relative to the mean cost because contractual agreements and institutional policies prohibit the publication of raw cost data. For similar reasons, publication of implant manufacturer names is prohibited.

Statistical methods

Descriptive summaries were provided for patient factors including age, race, sex, American Society of Anesthesiologists (ASA) classification, smoking status, and preoperative diagnosis of osteoporosis or osteoarthritis. Operative and postoperative factors evaluated included days from injury to fixation, fracture pattern type, number of plates, performance of an olecranon osteotomy or ulnar nerve transposition, ambulatory vs. inpatient setting, duration of surgery and anesthesia, and the treating service (hand vs. trauma).

Categorical variables were reported as frequency and percentage, whereas continuous variables were reported as mean and standard deviation (SD) or median and interquartile range (IQR) if the distribution is skewed. Our institution's raw cost data were converted to January 2019 US dollars using the Bureau of Economic Analysis personal consumption expenditure indices Health.[1] The mean SETDC for all surgeries was calculated, and ratios relative to this cost were calculated.

Associations between patient factors and SETDC were evaluated using univariable and multivariable linear regressions. Other distribution families, including Poisson, Gamma, and Inverse Gaussian were considered, but did not fit the data better than the Gaussian (linear) model, as assessed using a modified Park test.[26] A log link was used so that change in cost can be estimated as ratios.

Variables significantly associated with SETDC in the univariate analyses were used to construct the multivariate model. Potential multicollinearity of the multivariate model was checked using a variance inflation factor. Variables causing considerable multicollinearity (variance inflation factor > 2.5) due to high correlation with other variables were removed from the analysis.

Regression coefficients from both univariate and multivariate models were exponentiated to represent ratios in the outcome, which were reported with 95% confidence intervals (CIs) and *P* values.

Statistical significance was assessed at the 0.05 level, and all tests were 2 sided. All analyses were conducted in R 3.6.1.[35]

Table I
Descriptive summary of all patients (N = 47)

Variable	Value (%)
Age, mean (SD)	50.1 (21.2)
Race	
Nonwhite	4 (8.5)
White	43 (91.5)
Sex	
Female	25 (53.2)
Male	22 (46.8)
BMI, mean (SD)	29.3 (6.0)
ASA class	
1	13 (27.7)
2	14 (29.8)
3	18 (38.3)
4	2 (4.3)
Smoking	9 (19.6)
Payer mix	
Commercial	25 (54.3)
Medicare	14 (30.4)
Other	7 (15.2)
Osteoporosis diagnosis	9 (19.1)
Osteoarthritis of the elbow	11 (23.4)
Injury type	
Intra-articular, complex	38 (80.9)
Intra-articular, simple	4 (8.5)
Extra-articular	5 (10.6)
Olecranon osteotomy	17 (36.2)
Ulnar transposition	12 (25.5)
Number of plates, mean (SD)	2.0 (0.5)
Main fixation method	
Single plate	5 (10.6)
90°-90° dual plating	37 (78.7)
180° dual plating	5 (10.6)
Additional small plate as reduction aid	8 (17)
Number of nonlocking screws, mean (SD)	9.7 (4.4)
Number of locking screws, mean (SD)	5.1 (2.7)
Plate manufacturer	
A	45 (95.7)
B	2 (4.3)
Site	
Main hospital	46 (97.9)
Ambulatory surgical center	1 (2.1)
Surgical time in hours, mean (SD)	3.4 (1.2)
Anesthesia time in hours mean (SD)	4.8 (1.3)
Visit type	
Inpatient	37 (78.7)
23-h observation	5 (10.6)
Treating service	
Trauma	30 (63.8)
Hand	14 (29.8)
Shoulder and elbow	3 (6.4)
Open fracture	14 (29.8)
Anesthesia type	
General	46 (97.9)
Regional	1 (2.1)

BMI, body mass index; *ASA*, American Society of Anesthesiologists.

Results

Of the 47 patients included in this study, the mean age was 50.1 ± 21.2 years and 53.2% (25/47) of patients were female. The majority (97.9%; 46/47) of surgeries were performed at the main hospital. 89.4% (42/47) of surgeries were performed using 2 main plates in a 90°-90° (78.7%; 37/47) or 180° (10.6%; 5/47) construct. Five cases (10.6%) used a single plate for fixation, and these were extra-articular, or AO type A, fractures. Eight cases (17%) used an additional small plate as a reduction aid in the construct. Implant manufacturer A was used in 95.7% (45/47) of cases. An olecranon osteotomy was performed in 17 (36.2%) cases, and ulnar nerve transposition was performed in 12 (25.5%) cases. The majority (80.9%; 38/47) of fractures had complex intra-articular patterns. The mean number of plates, nonlocking screws, and locking screws were 2 ± 0.5, 9.7 ± 4.4, and 5.1 ±2.7 respectively. Additional patient, injury and surgical information is presented in Table I.

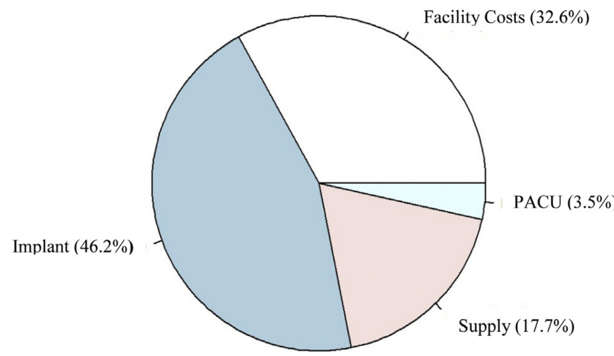

Figure 1 Breakdown of cost distribution by percentage.

Factors influencing surgical encounter total direct costs (SETDC)

Implant (46.2%) and facility (32.6%) costs made up the largest components of the SETDC (Fig. 1). Considerable variation in the SETDC for distal humerus ORIF was observed. Specifically, the standard deviation compared to the mean surgical cost of the whole cohort was 33%, and interquartile range was 76%-124%. Implant costs also varied considerably, with an SD of 21% and range from 13%-36% relative to the mean SETDC.

Univariate analysis demonstrated that the performance of an olecranon osteotomy significantly increased surgical encounter total direct costs by 54% (P < .001; 95% CI 1.34-1.77). Increased surgical and anesthesia time also increased costs by 22% (P < .001; 95% CI 1.16-1.27) and 20% (P < .001; 95% CI 1.15-1.26), respectively. Using 2 plates compared to one plate increased costs by 51% (P = .02; 95% CI 1.06-2.52). Using additional small plate/screw constructs as a reduction aid increased costs by 19%, though this was not statistically significant (P = .13; 95% CI 0.94-1.47). Outpatient or 23-hour observation status, as compared to inpatient status, was associated with a 29% cost reduction (P = .01; 95% CI 0.53-0.91). Patient demographics (age, sex, race, body mass index, smoking) were not associated with cost differences. Fracture- and surgery-specific factors, such as fracture pattern and open fracture, and the performance of an ulnar transposition, did not significantly impact costs (Table II).

Multivariate analysis revealed that performing an olecranon osteotomy was significantly associated with increased costs independent of other factors, increasing costs by 24% (P < .001; 95% CI 1.11-1.39). The number of plates used in the distal humerus fixation construct was no longer significant (P = .16; 95% CI 0.96-1.54). Duration of surgery also was an independent predictor of increased costs, with each additional hour of surgery increasing costs by 15% (P < .001; 95% CI 1.10-1.20). Differences in cost between inpatient and outpatient treatment were no longer significant (P = .36; 95% CI 0.78-1.08) (Table III).

Discussion

The primary aim of our study was to determine which factors are associated with variation in cost for open reduction internal fixation of distal humerus fractures. We found that substantial variation in total direct surgical costs exist in this setting. Relative to the mean surgical cost, the standard deviation for cost was substantial at 33%, and the interquartile range of surgical encounter costs was wide (76%-124%). Implants comprised the largest

Table II
Univariate analysis of factors impacting total direct cost

Variable	Ratio in cost	95% confidence interval	*P* value
Age*	1.01	(0.97-1.06)	.570
Race			
Nonwhite	Reference	—	—
White	1.07	(0.78-1.64)	.720
Sex			
Female	Reference	—	—
Male	1.01	(0.84-1.22)	.900
BMI	1.00	(0.98-1.02)	.970
ASA class			
1	Reference	—	—
2	0.95	(0.73-1.23)	.680
3+	1.03	(0.82-1.30)	.820
Smoking	1.16	(0.93-1.43)	.170
Osteoporosis	0.88	(0.66-1.12)	.350
Osteoarthritis	1.19	(0.96-1.44)	.100
Days from injury	0.99	(0.97-1.01)	.440
Injury type			
Extra-articular	Reference	—	—
Intra-articular, simple	1.27	(0.80-2.07)	.510
Intra-articular, complex	1.20	(0.88-1.84)	.510
Open fracture	1.15	(0.95-1.39)	.150
Number of main plates			
1	Reference	—	—
2	1.51	(1.06- 2.52)	.020
Olecranon osteotomy	1.54	(1.34-1.77)	<.001
Ulnar transposition	1.06	(0.85-1.30)	.580
Duration of surgery†	1.22	(1.16-1.27)	<.001
Duration of anesthesia†	1.20	(1.15-1.26)	<.001
Patient type			
Inpatient	Reference	—	—
23-h observation	0.71	(0.53-0.91)	.010
Treating service			
Hand	Reference	—	—
Trauma	0.91	(0.75-1.12)	.350

BMI, body mass index; *ASA*, American Society of Anesthesiologists.
* Per 10-year increments.
† Per 1-hour increments.

Table III
Multivariate analysis of factors affecting total direct cost

Variable	Ratio in cost	95% confidence interval	*P* value
Olecranon osteotomy	1.24	(1.11-1.39)	<.001
Duration of surgery*	1.15	(1.10-1.20)	<.001
Number of plates			
1	Reference	—	—
2	1.19	(0.96-1.54)	.160
Visit type			
Inpatient	Reference	—	—
23-h observation	0.93	(0.78-1.08)	.360

* Per 1-hour increments.

proportion of costs, at 46.2% of the total surgical cost, and also notable were supply costs, which includes drill bits and saw blades (17.7% of the total cost). Substantial cost variation for implants were also observed, with an SD of 21% and range from 13% to 36% relative to the mean SETDC.

Although we did not have enough variation in implant manufacturer at our institution to evaluate the contribution of this variable to cost variation, prior studies have shown that manufacturer significantly influences cost variation.[19]

Variation in cost is a common occurrence in orthopedic surgery.[16,19] Identification of factors that drive cost differences for various orthopedic conditions or injuries has been demonstrated in previously published studies.[19–21,27,48] Orthopedic surgeons consider cost to be an important factor when determining optimal treatment,[17,50] yet they have a poor understanding of factors that affect cost variation and are likely to underestimate costs.[4,33,43,50] Surgeon awareness of cost differences between implants used in distal humerus and other common upper extremity fractures may significantly impact a surgeon's choice of surgical implant.[50] In light of these findings, it is important to understand which other factors may be driving increased costs, as surgeons would likely be motivated to help decrease those costs associated with modifiable factors. Furthermore, our finding that 63.9% of the total costs related to distal humerus ORIF were attributed to supplies and implants alone highlights the opportunity to drive down surgical costs through judicious use of less costly implants, and by leveraging hospital bargaining power to negotiate for lower implant and supply pricing. This is of particular importance given the assumed equipoise between implant manufacturers, as there exists a lack of evidence supporting superiority of any one implant manufacturer in terms of yielding a better surgical outcome or lower complication profile, yet pricing likely differs.

We found that several surgical factors were associated with increased total direct costs for distal humerus ORIF, including olecranon osteotomy and overall surgical time. Performing an olecranon osteotomy was associated with increased surgical encounter costs independent of other factors, increasing costs by 24%. These findings are informative in light of Sharma et al's recent meta-analysis that found no difference in long-term functional outcomes and complication rates between olecranon osteotomy to non–olecranon osteotomy approaches in distal humerus ORIF.[39] The implication of these findings deserves caution, as none of the included studies were randomized controlled trials. Furthermore, the complex nature of these fractures often necessitates the performance of an olecranon osteotomy to help increase visualization of the articular surface, and fracture complexity is linked to use of an osteotomy, which makes it difficult to statistically differentiate between these 2 variables, as in the current study. An olecranon osteotomy may be more useful in AO Foundation / Orthopaedic Trauma Association type C2 and C3 fractures[29] and in older patients (age >60 years), and less likely indicated in type B and C1 fractures and younger patients (age <60 years).[8,46,52] Furthermore, although there was no significant difference in cost between simple and complex fracture types, the complexity of the fracture and use of an osteotomy are linked together. Although we found that fracture pattern was not a statistically significant driver of cost, we conclude that clinically it is a relevant factor as well as a statistically significant factor for fractures complex enough to warrant an osteotomy. In addition, the potential complications of olecranon osteotomy, including nonunion and symptomatic hardware, need to be considered, as they can also lead to additional costs long term. These factors were not included in the current study but are relevant from a societal cost perspective. Although we do not believe the decision to perform an olecranon osteotomy should be based on cost alone, we believe surgeons should carefully consider whether an osteotomy will either (1) allow for a better reduction and/or fixation, which may improve the long-term outcome, and (2) allow for a more efficient surgery and reduce time and cost of wasted attempts to achieve a reduction without an osteotomy.

Use of a small plate/screw construct as a reduction aid did not significantly increase costs in univariate or multivariate analysis. This finding should be interpreted with caution, however, and one should not deduce that additional plates add no additional cost for similar reasons as fracture pattern in the prior paragraph. Fracture severity, need for an additional plate, increased OR time, and need for an olecranon osteotomy are all linked. All patients needing an extra plate had complex fracture patterns. Therefore, surgeons should still carefully consider whether use of a provisional reduction plate will truly enhance stability of the construct or simplify fixation.

Not surprisingly, increased surgical time increased costs[5,10,19,21] associated with distal humerus ORIF. Each additional hour of operating time increased costs by 15%. As such, areas for improvement in OR efficiency should be explored.[20] Specific to teaching institutions, attending surgeons should find the right balance between educating future surgeons while maintaining efficiency in the OR.[2,12]

We also observed no significant difference in costs between inpatient vs. outpatient or 23-hour observation status. However, our analysis solely reflects PACU costs and did not capture costs directly related to the hospital stay. Therefore, it should not be concluded that an inpatient hospital stay is not more costly. Although prior studies have shown increased costs associated with a main hospital setting compared to ambulatory surgical centers,[31,32] we were unable to explore the effect of this variable as only 1 patient that had surgery at our ambulatory surgical center. We also did not observe a difference in surgical costs whether a formal ulnar nerve transposition was performed or not. This finding is informative in light of previous literature that concluded that ulnar nerve transposition in this setting is not protective of ulnar neuropathy.[40] The literature is conflicting, as other studies have supported this finding, whereas others have found no difference or improved outcomes with ulnar nerve transposition.[9,15,18,37,47,49] This statistically negative finding may be explained in terms of OR time: the main way a transposition would increase cost is through greater OR time, which was found to be a significant contributor to surgical cost. Therefore, although we did not find an increase in cost with ulnar nerve transposition, it increases OR time, which leads to greater cost, and surgeons must weigh the risks and benefits of transposition. Likewise, we did not find that open fractures increased cost of surgical treatment, but our study may have been underpowered to detect a difference of additional irrigation and débridement which would similarly manifest greater costs through increased OR time.

There are several study limitations that deserve mention. Although costs data were collected prospectively, the retrospective chart review design of this study introduces potential for selection bias. All cases were also performed at a single tertiary referral center by fellowship-trained orthopedic surgeons (shoulder and elbow, hand, and trauma), 80.9% were complex intra-articular patterns, and 29.8% were open fractures—this patient population may differ from that seen in other care settings. We were unable to study the effect of implant manufacturer on cost variation, as the majority of implants were derived from a single company. In addition, our study solely focuses on direct costs related to the surgical encounter itself. Therefore, factors affecting preoperative or postoperative costs, and professional payments, are not reflected by this study. As stated above, our patient population may differ from that of other hospital systems. Regional variability exists regarding OR and recovery protocols and staffing, and hospital-negotiated contract pricing for specific implants and supplies. Although the percentage increase of olecranon osteotomy or increased OR time may differ between institutions, it is likely these factors are clinically relevant at all institutions. Although the actual raw data of cost could not be disclosed because of contractual agreements at our institution, the impact of certain variables on cost can still be evaluated as a relative increase from a baseline value and has been used in other studies.[7,20,22,42,44] Lastly, this study was not designed as a cost-effectiveness analysis as we only evaluated surgical direct costs. Therefore, postoperative costs including those related to complications or time off of work were not considered, and the health state of each patient over time was not assessed. Thus, it remains unclear whether factors associated with greater cost, such as an olecranon osteotomy, lead to a better outcome or not.

Conclusion

There is an increasing focus in our current health care climate on improving cost-effective care without affecting outcomes or quality of care.[11,33,38] It is become increasingly important for surgeons to understand which modifiable factors can help decrease costs in treatment of specific conditions, and therefore decrease the overall burden to our health care system. We found that the majority of costs come from implants and supplies alone, and there is a large variation in surgical and implant costs. Olecranon osteotomy and duration of surgery also significantly affect the cost of distal humerus ORIF. The complexity of the fracture pattern, which is inherently associated with the need for olecranon osteotomy as well as an increase in surgical time, likely represents a clinically relevant and nonmodifiable driver of surgical cost. Therefore, surgeons should focus on carefully considering the need for olecranon osteotomy and using OR time efficiently. Measures to address sources of cost variation may improve the value of care delivered to patients.[5–7,16,19,45]

Disclaimer

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Supplementary Data

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