Patient Specific Costing of Total Ankle Arthroplasty vs Ankle Arthrodesis: Evaluating Modifiable Intra-Operative Cost Drivers Using Principles of Time-Driven Activity-Based Costing

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INTRODUCTION:

End-stage ankle osteoarthritis is commonly managed with ankle arthrodesis (AA) or total ankle arthroplasty (TAA), however robust cost analyses to identify areas of possible cost reduction and inform the value-based care transformation remain limited. Conventional costing models, such as Ratio of Costs to Charges (RCC) and traditional reimbursement metrics like relative value units (RVUs) often obscure the true sources of intraoperative expense. Time-Driven Activity-Based Costing (TDABC), a methodology that determines the cost of a process based on the cost of supplying a resource (e.g., orthopaedic surgeon) and the time required by that resource to perform each activity, enables a rigorous, granular assessment of resource utilization. In this study, we applied patient-specific costing using TDABC principles to compare total cost between AA and TAA and to uncover modifiable intraoperative cost drivers in surgical management of end-stage osteoarthritis.

METHODS:

In this study, 100 patients (50 AA, 50 TAA) were retrospectively analyzed. Clinical variables of age, BMI, diabetes, neuropathy, and other hindfoot arthritis were obtained. Cost inputs of length of stay (LOS), implant and supply costs, OR/surgeon time, 3-view ankle X-ray, ankle CT, and follow-up visits were derived or obtained from the institutional EHR, published TDABC studies, and publicly available hospital data. Proprietary institution data were reported in ratio format. Continuous measures were compared between AA and TAA using Mann–Whitney U tests (MWU). Categorical factors and variables with >50% zeros were dichotomized and analyzed via Chi-square or Fisher's exact test if expected counts for any group were less than 5. Patient-specific TDABC cost (PS-Cost) was modeled in separate AA-only and TAA-only multivariable generalized linear models (GLMs) with gamma family and log link. Predictors included modifiable counts (surgery time, LOS, total X-rays, CTs, follow-ups, post-complication visits, post-complication OR minutes, and complication-related hardware cost per $1,000) plus nonmodifiable covariates (age, BMI, diabetes, neuropathy, hindfoot arthritis, additional concomitant procedures). Percent-change values indicate the change in cost associated with a one-unit increase in each predictor.

RESULTS:

In univariate testing, PS-Cost significantly higher for TAA than AA (ratio 1.82; $P<0.001$). Implant cost (ratio 2.50; $P<0.001$), "Other Supplies" cost (ratio 1.71; $P<0.001$), and operative time (median 148 min vs. 102 min; $P<0.001$) were each higher for TAA. AA patients tended to have a greater number of concomitant procedures ($P=0.042$), while LOS trended longer in TAA (median 2 days vs. 0 days; $P=0.061$). In multivariable gamma-GLMs adjusting for age, BMI, diabetes, neuropathy, hindfoot arthritis, and additional procedures - length of stay (LOS) and surgery time remained independent cost drivers for both AA and TAA. In the AA model, each additional hospital day increased cost by 10.92% ($\beta = 0.104$, $P<0.001$) and each operative minute by 0.34% ($\beta = 0.003$, $P<0.001$). In TAA, LOS (+13.81% per day, $P<0.001$), surgery time (+0.40% per minute, $P=0.003$), additional hardware (per $1,000; +3.38%, $P=0.003$), and number of follow-ups (+3.30% each, $P=0.034$) were significant.

DISCUSSION AND CONCLUSION:

Both AA and TAA costs are driven primarily by length of stay and operative time; however, TAA incurs extra hardware and follow-up costs. Our findings show that reducing hospital stays, operative time, and implant-related expenses plays a key role in lowering PS-Cost for end-stage ankle arthritis surgery. Implementation of enhanced recovery after surgery protocols for earlier discharge and lower complication rates, optimizing OR workflows to shorten operative time, and value-based purchasing agreements with vendors may yield the largest reductions in cost. Future studies should validate our findings across multiple centers and expand the analysis to include additional preoperative, intraoperative, and postoperative cost elements.

Table 1: Univariate Comparison of Cost Components and Categorical Clinical Variables Between Ankle Arthrodesis (AA) and Total Ankle Arthroplasty (TAA)

Variable	AA Median	TAA Median	n AA	n TAA	Test	Statistic	p-value
PS-Cost $	a (Q1 = 0.80x, Q3 = 1.76x)	1.82x (Q1 = 1.91x, Q3 = 2.55x)	50	50	MWU	723.000	<0.001
Implant $	b (Q1 = 0.29x, Q3 = 1.33x)	2.50x (Q1 = 2.02x, Q3 = 2.98x)	50	50	MWU	400.000	<0.001
Other Supplies $	c (Q1 = 0.39x, Q3 = 1.72x)	1.71x (Q1 = 1.35x, Q3 = 3.85x)	50	50	MWU	769.000	<0.001
Surgery Time	102.00 (Q1 = 83.00, Q3 = 120.75)	148.00 (Q1 = 124.25, Q3 = 161.00)	50	50	MWU	434.500	<0.001
LOS	0.00 (Q1 = 1.00, Q3 = 3.00)	2.00 (Q1 = 0.00, Q3 = 5.00)	50	50	MWU	987.000	0.061
# Follow-ups	6.00 (Q1 = 5.00, Q3 = 9.00)	6.50 (Q1 = 4.00, Q3 = 7.75)	50	50	MWU	1154.500	0.509
Complication Related Surgery Time (min)			0	50	*	*	*
Additional Hardware Cost ($1000)			0	50	*	*	*
# XR	5	5	50	50	Chi-square	0.260	0.610
# CT	0	0	50	50	Chi-square	0.641	0.416
# Complication Related Follow-up	0	0	50	50	Chi-square	0.563	0.453
# Complication Related XR	0	0	50	50	Chi-square	0.563	0.453
# Complication Related CT	0	0	50	50	Chi-square	2.458	0.117
No Diabetes	-	-	43	44	Chi-square	0.000	1.000
Diabetes	-	-	7	6			
No Neuropathy	-	-	43	45	Fisher's	0.125	0.059
Neuropathy	-	-	7	5			
No Other Hindfoot Arthritis	-	-	40	39	Chi-square	0.000	1.000
Other Hindfoot Arthritis	-	-	10	11			
One Additional Procedure	-	-	27	15			
Two Additional Procedures	-	-	8	6			
Three Additional Procedures	-	-	2	1	Chi-square	11.500	0.042
Four Additional Procedures	-	-	1	0			
Five Additional Procedures	-	-	1	1			
No Additional Procedures	-	-	11	27			

*FDR inappropriate for MWU

Table 2: Generalized Linear Model of Cost Predictors for Ankle Arthrodesis (AA)

Predictor	Coef. (β)	Std. Err.	z	P>|z|	0.025	0.975	% change
Intercept	8.608	0.353	24.393	>0.001	7.916	9.299	547212.694
LOS (days)	0.104	0.009	11.501	>0.001	0.086	0.121	10.917
Surgery Time (min)	0.003	0.001	3.573	>0.001	0.002	0.005	0.339
BMI	0.012	0.006	1.840	0.066	-0.001	0.024	1.169
# CT	0.084	0.072	1.168	0.243	-0.057	0.226	8.788
Diabetes	-0.151	0.160	-0.945	0.345	-0.466	0.163	-14.055
Complication Related Surgery Time (min)	0.002	0.002	0.850	0.396	-0.002	0.005	0.164
Neuropathy	-0.117	0.152	-0.766	0.443	-0.415	0.182	-11.017
Other Hindfoot Arthritis	0.062	0.107	0.583	0.560	-0.147	0.272	6.428
# Complication Related Follow-up	0.021	0.041	0.506	0.613	-0.059	0.100	2.082
Age (years)	0.002	0.004	0.477	0.633	-0.005	0.009	0.175
Additional Hardware Cost ($1000)	0.012	0.028	0.443	0.658	-0.042	0.067	1.247
# XR	0.010	0.025	0.385	0.700	-0.039	0.058	0.965
# Follow-ups	0.005	0.023	0.226	0.821	-0.040	0.051	0.528
# Complication Related XR	0.007	0.042	0.168	0.866	-0.076	0.090	0.716
# Complication Related CT	-0.025	0.164	-0.154	0.878	-0.346	0.296	-2.484
Additional Procedure at same time	-0.005	0.045	-0.108	0.914	-0.092	0.083	-0.481

Table 3: Generalized Linear Model of Cost Predictors for Total Ankle Arthroplasty (TAA)

Predictor	Coef. (β)	Std. Err.	z	P>|z|	0.025	0.975	% change
Intercept	9.359	0.482	19.432	>0.001	8.415	10.303	1160468.754
LOS (days)	0.129	0.017	7.826	>0.001	0.097	0.162	13.807
Surgery Time (min)	0.004	0.001	3.016	0.003	0.001	0.007	0.396
Additional Hardware Cost ($1000)	0.033	0.011	2.942	0.003	0.011	0.055	3.375
# Follow-ups	0.032	0.015	2.122	0.034	0.002	0.062	3.299
Complication Related Surgery Time (min)	0.001	0.001	1.512	0.130	0.000	0.003	0.123
# CT	-0.075	0.053	-1.407	0.159	-0.180	0.030	-7.242
BMI	-0.010	0.008	-1.274	0.203	-0.025	0.005	-0.970
# XR	0.024	0.024	-0.986	0.324	-0.071	0.024	-2.356
Age (years)	0.004	0.004	0.923	0.356	-0.004	0.012	0.384
Additional Procedure at same time	-0.027	0.033	-0.813	0.416	-0.093	0.038	-2.675
Diabetes	-0.061	0.078	-0.778	0.436	-0.214	0.092	-5.891
Neuropathy	-0.168	0.258	-0.650	0.515	-0.674	0.338	-15.455
# Complication Related Follow-up	-0.010	0.031	-0.322	0.747	-0.071	0.051	-0.999
# Complication Related XR	-0.012	0.099	-0.310	0.757	-0.090	0.066	-1.224
# Complication Related CT	0.013	0.151	0.090	0.929	-0.282	0.309	1.359