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ORIGINAL RESEARCH

# Economic Burden and Healthcare Resource Use for Thoracic Aortic Dissections and Thoracic Aortic Aneurysms—A Population-Based Cost-of-Illness Analysis

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**BACKGROUND:** Thoracic aortic dissections (TADs) and thoracic aortic aneurysms (TAAs) are resource intensive. We sought to determine economic burden and healthcare resource use to guide health policy.

**METHODS AND RESULTS:** Using universal healthcare coverage data for Ontario, Canada, from 2003 to 2016, a cost-of-illness analysis was performed. From a single-payer's perspective, direct costs (hospitalization, reinterventions, readmissions, rehabilitation, extended care, home care, prescription drugs, and imaging) were assessed in 2017 Canadian dollars. Controls without TADs or TAAs were matched 10:1 on age, sex, and socioeconomic status to cases with TADs or TAAs to compare posthospital service use to the general population. Linear and spline regression were used for cost trends. Total hospital costs increased from $9 M to $20.7 M for TADs ($P<0.0001$) and $13 M to $18 M for TAAs ($P<0.001$). Costs cumulated to $587 M for 17 113 cases. Median hospital costs for TADs were $11 525 ($6102 medical, $26 896 endograft, and $30 372 surgery) with an increase over time ($P=0.04$). For TAAs, median costs were $16 683 ($7247 medical, $11 679 endograft, and $22 949 surgery) with a decrease over time ($P=0.03$). Home care was the most used posthospital service (TADs 44%, TAAs 38%), but rehabilitation had the highest median cost (TADs $11.9 M, TAAs $11 M). Men had increased median costs for indexed hospitalizations relative to women, yet women used more posthospital services with higher service costs.

**CONCLUSIONS:** Total yearly costs have increased for TADs and TAAs. Median hospital costs have increased for TADs yet decreased for TAAs. Women use posthospital healthcare services more often than men.

**Key Words:** aortic aneurysm ■ aortic dissection ■ cost-of-illness ■ economics ■ health policy ■ population studies ■ sex-differences

Treatment of thoracic aortic dissections (TADs) and thoracic aortic aneurysms (TAAs) are a formidable medical challenge for healthcare systems worldwide. The significant morbidity and mortality associated with these aortopathies are widely known.[1–3] Moreover, treatment of thoracic aortic disease is highly resource intensive. Together, these factors obligate substantial capital commitment by the healthcare sector for a disproportionately small percentage of the population. Although mindful of the issue, the proper allocation of healthcare services by the healthcare sector proves difficult. While TADs and TAAs are interconnected across the aortic continuum, they remain distinct entities with different clinical presentations that dictate variable management strategies—from emergent complex surgeries or endovascular interventions to nonurgent, anti-impulse medical management and imaging surveillance. Specialty care for the thoracic aorta adds another layer of complexity to budgetary concerns. Expertise to treat the thoracic aorta is

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For Sources of Funding and Disclosures, see page 21.

## CLINICAL PERSPECTIVE

### What Is New?

- The median and total yearly costs to treat thoracic aortic dissections as well as the total yearly costs to treat thoracic aortic aneurysms have increased beyond the rate of inflation, yet median costs for thoracic aortic aneurysms have decreased.
- After hospital treatment for a thoracic aortic dissection or thoracic aortic aneurysm, a higher percentage of women relative to men use posthospitalization healthcare services for recovery.
- Hospital readmissions are common for both surgery and endografting for this patient population within 1 year of hospital discharge. Reinterventions during a readmission incur the highest median cost relative to other commonly used posthospital services.

### What Are the Clinical Implications?

- Factors attributed to thoracic aortic dissection costs are likely to continue in an upward trajectory: increased incidence of disease, operative success in historically nonoperative patients, and evidence-directed endografting for type B dissection patients historically managed medically. The decreased median costs for thoracic aortic aneurysms is relatively marginal—a continued upward cost trend is predicted, and healthcare systems budgeting for thoracic aortic disease resource requirements should anticipate increased need.
- Sex-specific differences for thoracic aortic aneurysms and thoracic aortic dissections go beyond perioperative care with carryover into the posthospital recovery phase.
- Policies to counter escalating thoracic aortic care costs are best served by initiatives to reduce readmissions and specifically reinterventions as a key focus.

### Nonstandard Abbreviations and Acronyms

| | |
|---|---|
| ***CCI*** | *Canadian Classification of Health Interventions* |
| ***ICD*** | *International Statistical Classification of Diseases and Related Health Problems* |
| **ICES** | Institute for Clinical and Evaluative Sciences |
| **TAAs** | thoracic aortic aneurysms |
| **TADs** | thoracic aortic dissections |
| **TEVAR** | thoracic endovascular aortic repair |

dispersed across specialties (cardiac surgeons, cardiologists, interventional radiologists, and vascular surgeons) with synergistic but at times overlapping roles. This creates a multitude of access points to care and fosters nonstandardized treatment, redundant investigations, and an escalation in cost expenditures. Single-payer healthcare models, such as the Canadian system, as well as the private insurance–based hybrid system of the United States are both vulnerable to such cost inefficiencies.[4,5] Despite the importance of cost containment initiatives to direct treatment strategies for thoracic aortic disease, there is a paucity of data on healthcare utilization costs to guide health policy. With an aging population and an established increased incidence of thoracic aortic disease in Canada,[6] we performed a population-based cost-of-illness analysis to determine the economic burden and resource use for TADs and TAAs in the province of Ontario.

## METHODS

From a government single-payer's perspective, we performed a cost-of-illness analysis, incorporating a matched cohort comparative group for all posthospitalization comparisons. We used anonymously linked patient-level universal healthcare coverage information for people 18 years of age or older residing in the province of Ontario, Canada. All incident cases of TADs and TAAs between April 1, 2003 and March 31, 2016 were identified. Follow-up was until March 31, 2017 or patient death if such an event occurred prior to the study completion date. Cases were acquired by presentation to a hospital within the Ontario healthcare system. To be an incident case, a 5-year period without a diagnosis of the disease of interest was required. All substantive study data and analyses are provided herein. Access to supportive auxiliary data sets are available upon reasonable request to the corresponding author.

The primary outcome of interest was the median and total yearly cost for indexed hospitalizations to treat TADs and TAAs for the 13-year study. Secondary outcomes included the proportional healthcare service use and median costs for 7 postindexed hospitalization services: readmissions, rehabilitation, complex continuing care, long-term care, home care services, prescription drugs, and computed tomography/magnetic resonance imaging surveillance studies. Precise definitions for the posthospitalization services focused on physical conditioning and general health are listed in Table 1.

A matched cohort was derived to allow for a comparative analysis of the 7 posthospitalization healthcare services to the general population. People without TADs or TAAs within the Ontario population (13.8 million people) were matched 10:1 for age, sex,

**Table 1. Posthospitalization Healthcare Services Provided in Ontario, Canada**

| |
|---|
| 1. *Rehabilitation services* facilitate health recovery and are provided for all hospital rehabilitation inpatients as well as hospital-registered outpatients at registered outpatient clinics. This may include, among other services, physiotherapy, occupational therapy, and speech language pathology. |
| 2. *Complex continuing care* refers to chronic care and is provided in hospitals for people who have long-term illnesses or disabilities typically requiring skilled care not available at home or in long-term care facilities. Chronic care provides patients with room, board, and other necessities in addition to medical care. |
| 3. *Long-term care* facilities are out-of-hospital care homes where people can live and are provided 24-hour nursing and personal care for assistance with daily activities. |
| 4. *Home care* encapsulates a variety of minor medical services provided to people at their home on a required need basis after a registered hospital admission. |

and socioeconomic status to incident cases with TADs or TAAs. Matching occurred at the time of the indexed hospitalization for incident cases. Healthcare resource use costs acquired within 1 year of hospital discharge for the 7 specified healthcare services were compared across incident cases and the matched comparative cohort. Patients who died during the indexed hospitalization were not included in the matched comparative analysis assessing secondary outcomes, as patient death inherently negates additional resource use. However, for the primary outcome of median and yearly indexed hospital costs, all cases, including cases of hospital death, were included in the analysis.

Costs incurred at the indexed hospitalization included all hospital services from time of admission with an incident case to the time of discharge from the treating hospital network. Hospital-to-hospital transfer fees and emergency department services were included in the indexed hospitalization cost. Costs were stratified across treatment strategy (medical, endovascular, open surgery), and trends were assessed over time. Reinterventions (defined as any endovascular or surgical therapy >72 hours after the initial endovascular or surgical procedure) were captured within the indexed hospitalization if no discharge had occurred prior to the reintervention. Reinterventions were also assessed separately as a specific subcategory of cost unto itself.

Prescription drugs relevant to the pharmacologic treatment of TADs and TAAs after discharge from the indexed hospitalization (oral antihypertensive and lipid-lowering agents) were also assessed.[7] The following 6 categories of medication were captured: (1) beta-blockers, (2) calcium channel blockers, (3) angiotensin converting enzyme inhibitors, (4) angiotensin II receptor blockers, (5) diuretics, and (6) statins and associated antilipidemic drugs (Table S1). Of note, in-hospital prescription medications and any out-of-hospital prescription medications for people 65 years of age or older would be covered by the Ontario healthcare system, and thus such costs are captured within the analysis. People of any age in long-term care facilities or disabled with a need for financial assistance may also qualify and would also be captured. All other medications are paid out of pocket in Ontario and were not a direct cost to the healthcare system; thus, they were not considered in this study.

Access to the linked administrative data sets was through the Institute for Clinical Evaluative Sciences (ICES), where person-specific encrypted health identifier numbers enabled deidentified patient-level health information to be acquired for the cohort of interest and the matched comparison cohort. The data sets used and the types of data acquired for each data set are listed in Table S2. Research ethics boards of the University of Calgary, Queen's University, and Sunnybrook Hospital approved the study. Informed patient consent was waived and not required given the deidentified nature of the study.

The methods to capture incident cases of TADs and TAAs have previously been described[6] (Figure 1). The systematic algorithm to distinguish between a Stanford type A and a Stanford type B aortic dissection, once an incident case of an aortic dissection was identified, is also detailed elsewhere[6] (Table 2). Briefly, the medical diagnosis at presentation to a hospital was captured with the *International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada* codes (*ICD-10-CA*) (Table S3). Thereafter, an intervention to a specific segment of the aorta with surgery or an endovascular procedure was captured through the Canadian Classification of Health Interventions (CCI) coding system (Table S3). Relevant diagnosis codes for aortic dissections and aortic aneurysms (*ICD* codes) were available dating back to 1992, whereas relevant procedural codes (*Canadian Classification of Health Interventions codes* [*CCI codes*]) were available in late 2002. Having *ICD* codes predate *CCI* codes facilitated the 5-year "disease free" inclusion criteria and substantially mitigated the potential for penetrance of chronic disease into the cohort.

The size criterion to determine whether an aorta was aneurysmal was at the discretion of the treating physicians at the time of hospital admission. Moreover, the size threshold at which to perform a surgical or endovascular intervention was also at the discretion of the treating physicians. If an endovascular or surgical procedure was not coded to coincide with the diagnosis, optimal medical therapy was the presumed treatment strategy.

## Cost Data and Statistical Analysis

An established and validated person-level costing algorithm for the ICES data sets was implemented.[8] Unit costs for healthcare services were obtained from the

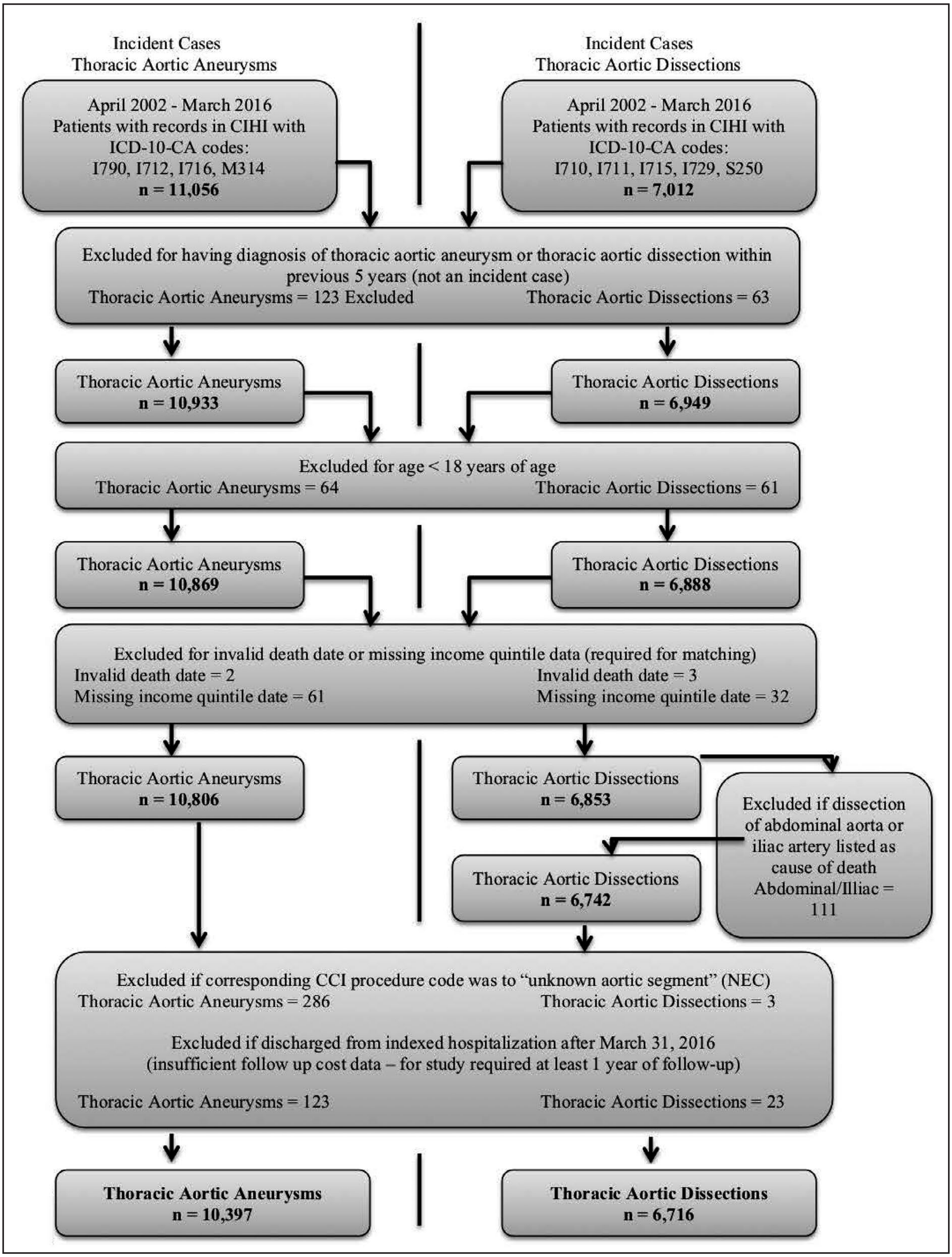


**Figure 1. Flow diagram depicting the acquisition of incident cases of thoracic aortic dissections and thoracic aortic aneurysms.**

CCI indicates Canadian Classification of Health Interventions; CIHI, Canadian Institute for Health Information; *ICD-10-CA*, *International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada*; and NEC, not elsewhere classified.

**Table 2. Algorithm to Determine if an Aortic Dissection Was Stanford Type A or Type B**

| | | |
|---|---|---|
| Aortic Dissection Classification Algorithm (*ICD-10-CA*+CCI codes) | | |
| If Diagnosis of an Aortic Dissection from *ICD-10-CA* Codes | | |
| AND | | |
| Have 1 Associated Procedural Code (CCI Code) | | |
| (i) CCI code=Surgery or TEVAR for AscA | *then* | Type A Dissection |
| (ii) CCI code=Surgery/TEVAR for AArch | *then* | Type A Dissection |
| (iii) CCI code=Surgery/TEVAR for DTA | *then* | Type B Dissection |
| If Diagnosis of an Aortic Dissection from *ICD-10-CA* Codes | | |
| AND | | |
| Have 2 or 3 Associated Procedural Code (CCI Codes) (on same day) | | |
| (i) CCI codes=Surgery/TEVAR for AscA+AArch | *then* | Type A Dissection |
| (ii) CCI codes=Surgery/TEVAR for AscA+DTA | *then* | Type A Dissection |
| (iii) CCI codes=Surgery/TEVAR for AscA+AArch+DTA | *then* | Type A Dissection |
| If Diagnosis of an Aortic Dissection from *ICD-10-CA* Codes | | |
| AND | | |
| Have No Associated Procedural Code (CCI Code)=No Intervention | | |
| AND | | |
| PATIENT ALIVE at discharge | | |
| (i) Then patient received medical management | *therefore* | Type B Dissection |
| If Diagnosis of an Aortic Dissection from *ICD-10-CA* Codes | | |
| AND | | |
| Have No Associated Procedural Code (CCI Code)=No Intervention | | |
| AND | | |
| PATIENT DIED during hospital admission | | |
| (i) Then assess ORGD for primary cause of death to determine if Type A or B Dissection | | |

AArch indicates aortic arch; AscA, ascending aorta; CCI, Canadian Classification of Health Interventions; DTA, descending thoracic aorta; *ICD-10-CA*, International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada; ORGD, Office of the Registrar—General Death Database; and TEVAR, thoracic endovascular aortic repair.



Ontario Ministry of Health and Long-Term Care. The direct costs of relevance covered under the single-payer health plan were monetized and included hospitalization costs, same-day surgery, emergency department visits, physicians' services, prescription medications, laboratory tests, rehabilitation, continuing care, long-term care facilities, home care services, and medical device data. Hospital and emergency department visits were calculated by multiplying the resource intensity weight by the cost per weighted case.[8] Fee-for-service costs were captured from payments through the Ontario Health Insurance Plan. Salaried or alternate payment plans were also assessed.[9] Imaging costs were captured through cross-referencing Ontario Health Insurance Plan billing payments with the imaging procedure of interest. Extended care services (complex continuing care and long-term care) had costs calculated as a fixed per diem based on government rates within the specified timeframe.

Categorical and dichotomous variables are presented as numbers and percentiles. Continuous variables are presented as the mean±SD. Descriptive data and treatment strategies were assessed with chi squared tests for differences across age, sex, and place of residence. McNemar's test was used for comparative analysis between incident cases and the matched comparative cohort. Linear and spline regressions were used for total annual cost trends and median cost trends, respectively. For spline regressions, *P* values were obtained using the generalized additive model. Cost data were reported in 2017 Canadian dollars. All statistical tests were 2-sided. Statistical significance was achieved with a *P* value of <0.05. To ensure patient anonymity, absolute numbers were not reported for categorical data that resulted in cells of <6. Where data did result in cells of <6, select adjacent data cells were presented as a numeric range as opposed to a single numeric value to negate the unmasking of these small cells through mathematical computation. All analyses were performed using SAS, version 9.4 (SAS Institute Inc., Cary, NC).

## RESULTS

There were 6716 TADs and 10 397 TAAs for a total of 17 113 incident cases. Within the TAD group, 2607

**Table 3. Demographics for Thoracic Aortic Dissection Cohort and the Match Comparison Cohort (2003–2016)**

| Characteristics | | Thoracic Aortic Dissections | | | | *P* Value | Matched Controls |
|---|---|---|---|---|---|---|---|
| | | Type A | Type B | Unknown | All | | |
| | | N=2607 | N=4083 | N=26 | N=6716 | | N=67 160 |
| Age, y | Mean±SD | 68.06±15.17 | 65.56±16.41 | 67.31±17.77 | 66.53±15.99 | 0.986 | 66.53±15.99 |
| | <50 | 334 (12.8%) | 680 (16.7%) | <6 (0%–19%) | 1014–1019 (15%) | 0.988 | 10 146 (15.1%) |
| | 50–74 | 1237 (47.4%) | 1985 (48.6%) | 13 (50.0%) | 3235 (48.2%) | … | 32 412 (48.3%) |
| | 75+ | 1036 (39.7%) | 1418 (34.7%) | <10 (0%–39%) | 2454–2463 (37%) | … | 24 602 (36.6%) |
| Age, y 65+ (health sector covers drug costs) | | 1634 (62.7%) | 2345 (57.4%) | 17 (65.4%) | 3996 (59.5%) | 0.909 | 39 912 (59.4%) |
| Sex | Female | 1022 (39.2%) | 1600 (39.2%) | 14 (53.8%) | 2636 (39.2%) | 1 | 26 360 (39.2%) |
| | Male | 1585 (60.8%) | 2483 (60.8%) | 12 (46.2%) | 4080 (60.8%) | | 40 800 (60.8%) |
| SES quintile | 1 (lowest) | 495 (19%) | 890 (21.8%) | <6 (0%–19%) | 1385–1390 (21%) | 1 | <13 910 (<20.7%) |
| | 2 | 528 (20.3%) | 861 (21.1%) | 10 (38.5%) | 1399 (20.8%) | … | 13 990 (20.8%) |
| | 3 | 517 (19.8%) | 731 (17.9%) | <6 (0%–19%) | 1248–1253 (19%) | … | <12 540 (<18.7%) |
| | 4 | 537 (20.6%) | 797 (19.5%) | 6 (23.1%) | 1340 (20.0%) | … | 13 400 (20.0%) |
| | 5 (highest) | 530 (20.3%) | 804 (19.7%) | <6 (0%–19%) | 1334–1339 (20%) | … | <13 400 (<20%) |
| Patient residence | Urban | 2240 (85.9%) | 3465 (84.9%) | 20–26 (77%–100%) | 5725–5731 (85%) | <0.001 | 58 752 (87.5%) |
| | Rural | 367 (14.1%) | 618 (15.1%) | <6 (0%–19%) | 985–990 (15%) | … | 8408 (12.5%) |
| COPD | | 743 (28.5%) | 1142 (28.0%) | 8 (30.8%) | 1893 (28.2%) | <0.001 | 10 160 (15.1%) |
| Diabetes mellitus | | 530 (20.3%) | 899 (22.0%) | <6 (0%–19%) | 1429–1434 (21%) | 0.001 | 13 213 (19.7%) |
| Hyperlipidemia | | 714 (27.4%) | 1146 (28.1%) | <6 (0%–19%) | 1860–1865 (28%) | <0.001 | 15 348 (22.9%) |
| Hypertension | | 2083 (79.9%) | 3127 (76.6%) | 16 (61.5%) | 5226 (77.8%) | <0.001 | 33 115 (49.3%) |
| Treatment | Surgery | 1402 (53.8%) | 431 (10.6%) | 0 (0.0%) | 1833 (27.3%) | … | |
| | TEVAR | 40 (1.5%) | 348 (8.5%) | 0 (0.0%) | 388 (5.8%) | | |
| | Medical management | 1165 (44.7%) | 3304 (80.9%) | 26 (100%) | 4495 (67%) | | |
| Thoracoabdominal procedures | | <6 (0%–0.2%) | 110–115 (2.7%–2.8%) | <6 (0%–19%) | 110–125 (1.6%–1.9%) | | |
| Death during indexed hospitalization/emergency department visits | | 1432 (54.9%) | 333 (8.2%) | 22 (84.6%) | 1787 (26.6%) | … | |
| Death within 1 y of indexed hospitalization/emergency department visit | | 1508 (57.8%) | 815 (20.0%) | 26 (100%) | 2349 (35.0%) | | |

Percentages are column percents. *P* values and standardized differences relate to comparisons between thoracic aortic dissection "All" column and matched controls. To maintain anonymity for small cells of <6 data points, some data have been presented as a numeric range, not a single numeric value. COPD indicates chronic obstructive pulmonary disease; SES, socioeconomic status; and TEVAR, thoracic endovascular aortic repair.

cases (39%) were Stanford type A dissections and 4083 were Stanford type B dissections (61%). The demographics for TADs are listed in Table 3, and the demographics for TAAs are listed in Table 4. For TADs, the mean age was 67 years, of which 85% of patients were 50 years of age or older. The majority of patients were men (61%), hypertensive (78%), and resided in urban residences (85%). Surgery was performed in 54% of type A aortic dissections (1402 of 2607) with an additional 1.5% receiving an endovascular intervention (40 of 2607). For type B aortic dissections, medical therapy was the predominant treatment strategy at 81% (3304 of 4083) followed by 11% open surgery (431 of 4083) and 9% thoracic endovascular aortic repair (TEVAR) (348 of 4083).

For TAAs, similar characteristics were identified. The mean age for TAA patients was 68, with 89% of patients 50 years of age or older. Urban residence (86%), hypertension (78%), and male sex (65%) were again predominant. Open surgery or TEVAR were used to treat 52% of TAAs (5410 of 10 683) versus 48% optimal medical therapy. For surgically treated aneurysms, 85% had an aneurysmal ascending segment (4110 of 4820), 4% (210 of 4820) had an aneurysmal arch, and 10% had an aneurysmal descending thoracic aorta (500 of 4820). Conversely, for aneurysms treated with TEVAR, 93% (550 of 590) were to treat the descending thoracic aorta, with only 5% (32 of 590) and 1% (8 of 590) to treat the arch and ascending aortic segments, respectively. Open

**Table 4. Demographics for Thoracic Aortic Aneurysm Cohort and the Matched Comparison Cohort (2003–2016)**

| Characteristics | | Thoracic Aortic Aneurysms | | | | | *P* Value | Matched Controls |
|---|---|---|---|---|---|---|---|---|
| | | Ascending | Arch | Descending | Unknown | All | | |
| | | N=4118 | N=242 | N=1050 | N=4987 | N=10 397 | | N=103 970 |
| Age, y | Mean±SD | 62.69±13.40 | 65.17±12.93 | 68.14±12.08 | 71.57±14.17 | 67.56±14.26 | 0.901 | 67.54±14.26 |
| | <50 | 638 (15.5%) | 26 (10.7%) | 87 (8.3%) | 411 (8.2%) | 1162 (11.2%) | 0.987 | 11 658 (11.2%) |
| | 50–74 | 2631 (63.9%) | 155 (64.0%) | 621 (59.1%) | 2070 (41.5%) | 5477 (52.7%) | ... | 54 805 (52.7%) |
| | 75+ | 849 (20.6%) | 61 (25.2%) | 342 (32.6%) | 2506 (50.3%) | 3758 (36.1%) | ... | 37 507 (36.1%) |
| Age, y 65+ (health sector covers drug costs) | | 2043 (49.6%) | 147 (60.7%) | 736 (70.1%) | 3672 (73.6%) | 6598 (63.5%) | 0.961 | 65 955 (63.4%) |
| Sex | Female | 1113 (27.0%) | 79 (32.6%) | 338 (32.2%) | 2083 (41.8%) | 3613 (34.8%) | 1 | 36 130 (34.8%) |
| | Male | 3005 (73.0%) | 163 (67.4%) | 712 (67.8%) | 2904 (58.2%) | 6784 (65.2%) | ... | 67 840 (65.2%) |
| SES quintile | 1 (lowest) | 641 (15.6%) | 49 (20.2%) | 206 (19.6%) | 1070 (21.5%) | 1966 (18.9%) | 1 | 19 660 (18.9%) |
| | 2 | 822 (20.0%) | 46 (19.0%) | 231 (22.0%) | 976 (19.6%) | 2075 (20.0%) | ... | 20 750 (20.0%) |
| | 3 | 838 (20.3%) | 57 (23.6%) | 204 (19.4%) | 939 (18.8%) | 2038 (19.6%) | ... | 20 380 (19.6%) |
| | 4 | 876 (21.3%) | 42 (17.4%) | 215 (20.5%) | 1015 (20.4%) | 2148 (20.7%) | ... | 21 480 (20.7%) |
| | 5 (highest) | 941 (22.9%) | 48 (19.8%) | 194 (18.5%) | 987 (19.8%) | 2170 (20.9%) | ... | 21 700 (20.9%) |
| Patient residence | Urban | 3579 (86.9%) | 221 (91.3%) | 903 (86.0%) | 4272 (85.7%) | 8975 (86.3%) | 0.001 | 90 904 (87.4%) |
| | Rural | 539 (13.1%) | 21 (8.7%) | 147 (14.0%) | 715 (14.3%) | 1422 (13.7%) | ... | 13 066 (12.6%) |
| COPD | | 730 (17.7%) | 68 (28.1%) | 425 (40.5%) | 1773 (35.6%) | 2996 (28.8%) | <0.001 | 16 233 (15.6%) |
| Diabetes mellitus | | 962 (23.4%) | 52 (21.5%) | 266 (25.3%) | 1256 (25.2%) | 2536 (24.4%) | <0.001 | 21 802 (21.0%) |
| Hyperlipidemia | | 1561 (37.9%) | 100 (41.3%) | 443 (42.2%) | 1624 (32.6%) | 3728 (35.9%) | <0.001 | 25 120 (24.2%) |
| Hypertension | | 2934 (71.2%) | 187 (77.3%) | 896 (85.3%) | 4058 (81.4%) | 8075 (77.7%) | <0.001 | 53 502 (51.5%) |
| Treatment | Surgery | 4110 (99.8%) | 210 (86.8%) | 500 (47.6%) | 0 (0.0%) | 4820 (46.4%) | | |
| | TEVAR | 8 (0.2%) | 32 (13.2%) | 550 (52.4%) | 0 (0.0%) | 590 (5.7%) | | |
| | Medical Management | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 4987 (100%) | 4987 (48.0%) | | |
| Thoracoabdominal procedures | | <6 (<0.2%) | <6 (<2.5%) | 306–311 (29.1%–29.6%) | 0 (0.0%) | 311 (3.0%) | | |
| Death during indexed hospitalization/ED visit | | 92 (2.2%) | 23 (9.5%) | 76 (7.2%) | 454 (9.1%) | 645 (6.2%) | | |
| Death within 1 y of indexed hospitalization/ED visit | | 199 (4.8%) | 35 (14.5%) | 173 (16.5%) | 1251 (25.1%) | 1658 (15.9%) | | |

Percentages are column percents. *P* values and standardized differences relate to comparisons between thoracic aortic aneurysm "All" column and matched controls. To maintain anonymity for small cells of <6 data points (thoracoabdominal procedures), some data have been presented as a numeric range, not single a numeric value. COPD indicates chronic obstructive pulmonary disease; ED, emergency department; SES, socioeconomic status; and TEVAR, thoracic endovascular aortic repair.

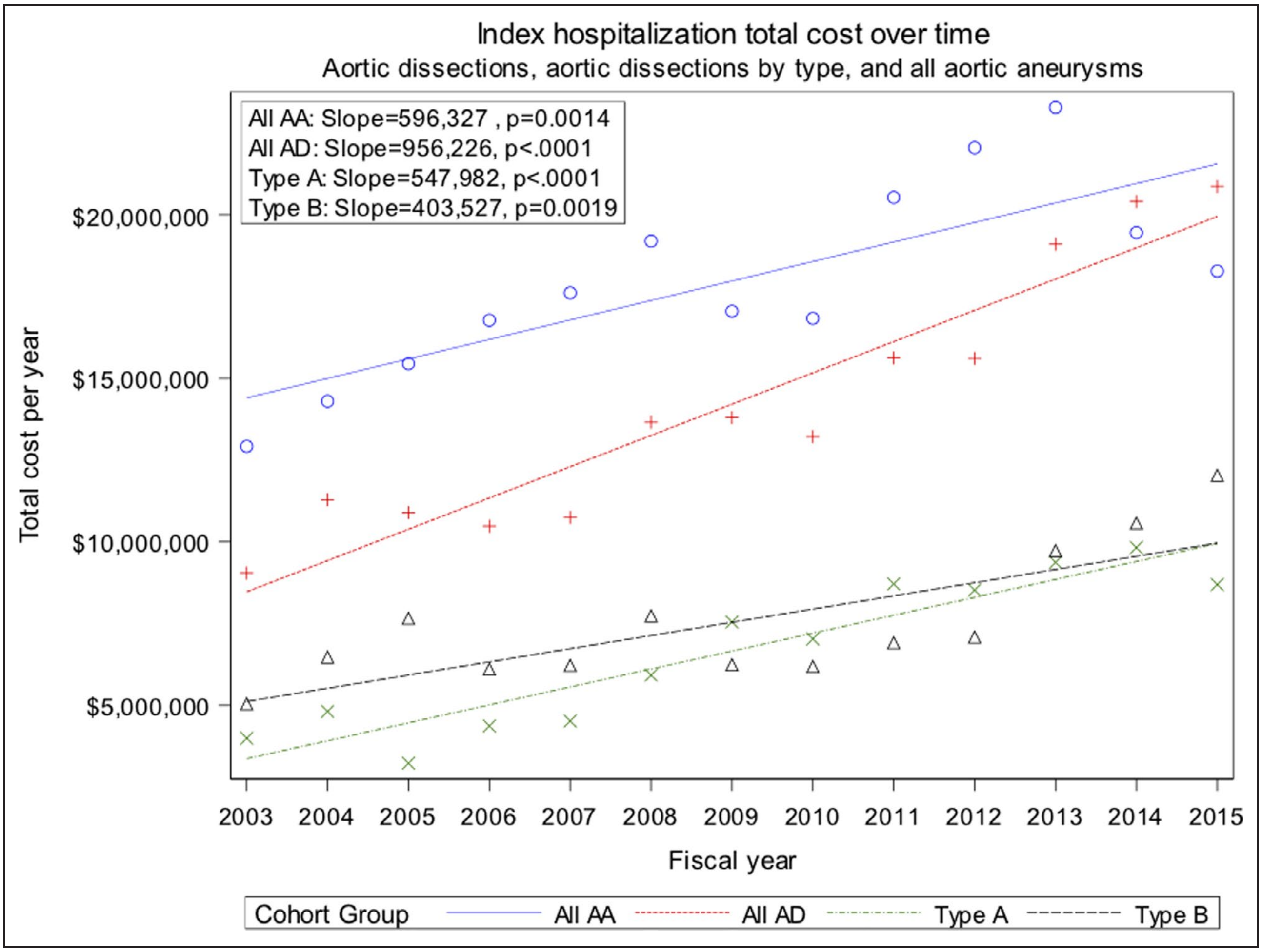


**Figure 2. Index hospitalization yearly total costs for the treatment of thoracic aortic dissections and thoracic aortic aneurysms in Ontario, Canada (2003–2016; Canadian dollars).**
AA indicates aortic aneurysm; and AD, aortic dissection.

thoracoabdominal procedures occurred in 29% of the descending TAA cohort that underwent a nonmedical management strategy (underwent surgery or TEVAR).

## Healthcare Utilization Costs

Total healthcare utilization costs (indexed hospitalizations+7 posthospitalization services) for the treatment of TADs and TAAs during the 13-year study was $587.3 million. A total of $245.7 million was spent on TADs, and $341.6 million was spent on TAAs. For TADs, type A dissections consumed $103.9 million of the cost expenditures, whereas type B dissections consumed 141.8 million. Surgery to treat TADs and TAAs accounted for $312.1 million, TEVAR $50 million, and medical therapy $225.2 million.

## Indexed Hospitalization Costs

The yearly total costs for indexed hospitalizations to treat TADs and TAAs significantly increased over time (Figure 2). The costs of TADs increased from $9 million in 2003 to $20.7 million in 2016 ($P$<0.0001). This equates to a year-over-year annual increase of 10%. These increased hospitalization costs were observed for both type A and type B dissections (type A, $4–$8.7 million [$P$<0.0001]; type B, $5–$12 million [$P$<0.002]). For the same time period, the yearly total costs for indexed hospitalizations with TAAs also increased from $12.9 million to $18.2 million ($P$=0.001) or a year-over-year annual increase of 3%.

Despite the uniform upward slopes and increased trends for yearly total costs with respect to indexed hospitalizations, the yearly median costs showed a degree of variability across the different disease entities (Figure 3). For TADs, similar to the yearly total costs, the yearly median indexed hospitalization costs significantly increased ($8834 in 2003 to $13 955 in 2016 [$P$=0.04]). This was primarily driven by type A dissections. The yearly median costs for indexed hospitalizations with type A dissections increased from $10 967 to $24 579 ($P$<0.0001). Type B dissections, on the other

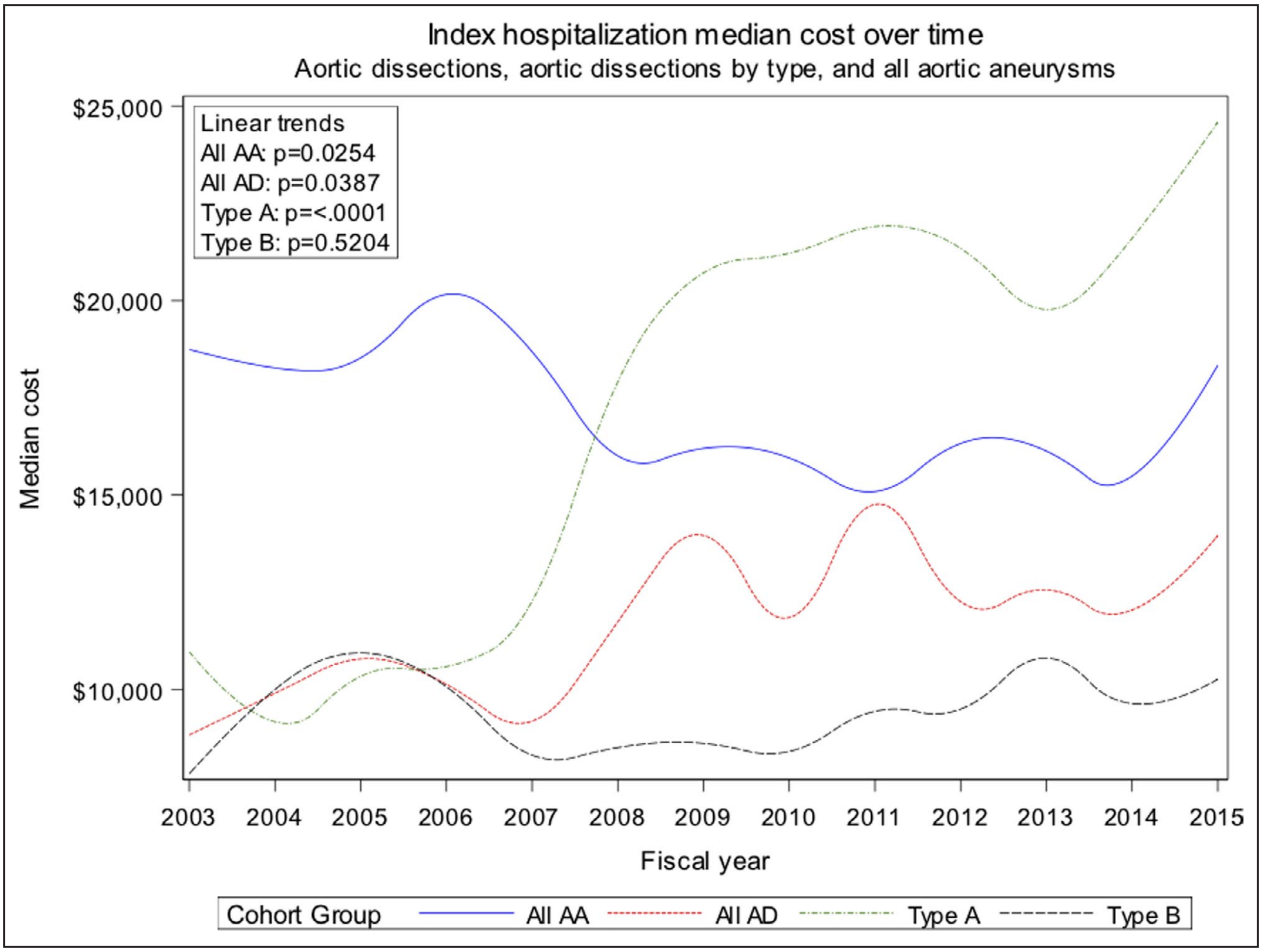


**Figure 3. Index hospitalization yearly median costs for the treatment of thoracic aortic dissections and thoracic aortic aneurysms in Ontario, Canada (2003–2016; Canadian dollars).**
AA indicates aortic aneurysm; and AD, aortic dissection.

hand, showed an upward but nonsignificant trend ($7835 to $10 261 [*P*=0.52]). For TAAs, counter to the observed increase for yearly total costs over time, the yearly median costs displayed a significant decrease in index hospitalizations costs during the study period ($18 741 to $13 955 [*P*=0.025]).

Beyond the aforementioned year-to-year trend analyses, the overall median costs to the healthcare system also had variation across TADs and TAAs, with further variation based on treatment strategies. For TADs, the overall median cost for indexed hospitalizations was $11 525, and for TAAs it was $16 683 (Tables 5 and 6). Specific to TADs, surgery had the highest median cost at $30 372, followed by TEVAR at $26 896 and medical therapy at $11 525. When stratified by sex, the median costs were comparable for the management of TADs across treatment modalities (surgery, TEVAR, or medical management). Despite this, the overall median costs were higher for men ($13 663 for men; $8570 for women; Table 5). When stratified by age, there was a decrease in median costs as patients got older ($16 811 for people younger than 50 years of age versus $7838 for people 75 years of age and older), likely attributable to a more conservative approach with less invasive treatment strategies in the elderly population. In support of this theory, open surgery had a direct increase in TAD hospitalization costs with increasing age ($27 055 for people younger than 50 years of age versus $38 648 for people 75 years of age and older; Table 5). Interestingly, when faced with a TAD, TEVAR was most costly for patients younger than 50 years of age (Table 5).

For TAAs, open surgery was again the highest expenditure with a median cost of $22 949, followed by TEVAR at $11 679 and medical therapy at $7247 (Table 6). Median cost expenditures for TAAs across sex and age stratifications were similar to those identified for TADs. Men, relative to women, incurred higher median hospitalization costs. Increasing age was again

**Table 5. Median Index Hospitalization Costs for Thoracic Aortic Dissections in Ontario, Canada by Treatment Strategy—Stratified by Sex, Age, and Place of Residence (2003–2016)**

| Thoracic Aortic Dissections | Median Indexed Hospitalization Costs by Treatment Strategy (2017 Canadian Dollars) | | | |
|---|---|---|---|---|
| | Overall | Surgery | TEVAR | Medical Therapy |
| Total cohort | $11 525 | $30 372 | $26 896 | $6102 |
| Stratified by sex | | | | |
| Male | $13 663 | $29 568 | $27 431 | $6670 |
| Female | $8570 | $32 852 | $26 472 | $5594 |
| Stratified by age, y | | | | |
| <50 | $16 811 | $27 055 | $40 302 | $5727 |
| 50–74 | $14 085 | $29 610 | $20 068 | $6638 |
| 75+ | $7838 | $38 648 | $29 192 | $5806 |
| Stratified by residence | | | | |
| Urban | $11 436 | $30 779 | $26 472 | $6125 |
| Rural | $12 099 | $28 764 | $28 237 | $5938 |

TEVAR indicates thoracic endovascular aortic repair.

reflective of an overall decrease in hospitalization costs, but an increase in surgical costs. For TEVAR, converse to what was seen with TADs, the cost of TEVAR increased similar to surgical costs with increasing age of TAA patients (Table 6). Median costs were comparable across place of residence for both disease processes (Tables 5 and 6).

## Postindex Hospitalization Resource Use

Readmissions, reinterventions, and 7 posthospitalization services were assessed (Tables 7 and 8). For patients undergoing surgery or TEVAR, a readmission to the hospital within 1 year of the initial procedure was common, although the need for reinterventions on such readmissions were low. Surgery resulted in 14.4% and 22.4% rates of readmissions for TADs and TAAs, respectively, with TEVAR rates even higher at 27.2% and 32.9%. Reinterventions were twice as likely with TEVAR (6.6%) versus surgery (3.2%) for TADs and 6 times as likely for TAAs (7.2% TEVAR versus 1.2% surgery; Tables 7 and 8). Reinterventions were costly to the healthcare system. For TADs, the overall median cost for reinterventions was $29 073 (surgery $24 547, TEVAR $34 475) and for TAAs $25 457 (surgery $27 030, TEVAR $22 616).

**Table 6. Median Index Hospitalization Costs for Thoracic Aortic Aneurysms in Ontario, Canada, by Treatment Strategy—Stratified by Sex, Age, and Place of Residence (2003–2016)**

| Thoracic Aortic Aneurysms | Median Indexed Hospitalization Costs by Treatment Strategy (2017 Canadian Dollars) | | | |
|---|---|---|---|---|
| | Overall | Surgery | TEVAR | Medical Therapy |
| Total cohort | $16 683 | $22 949 | $11 679 | $7247 |
| Stratified by sex | | | | |
| Male | $18 875 | $22 949 | $10 955 | $7989 |
| Female | $11 006 | $23 273 | $12 647 | $6623 |
| Stratified by age, y | | | | |
| <50 | $21 119 | $22 001 | $8146 | $11 919 |
| 50–74 | $20 484 | $22 879 | $11 906 | $8325 |
| 75+ | $9144 | $24 228 | $11 951 | $6589 |
| Stratified by residence | | | | |
| Urban | $16 852 | $22 956 | $11 335 | $7284 |
| Rural | $16 000 | $22 557 | $13 621 | $7126 |

TEVAR indicates thoracic endovascular aortic repair.

For the 7 posthospitalization services, follow-up beyond the indexed hospitalization was available for 4929 TAD patients and 9752 TAA patients. The 1-year median cost for posthospitalization services was significantly higher for TAD and TAA cases relative to the matched comparison cohort (TADs $2026, comparison cohort $584 [*P*<0.01]; TAAs $1838, comparison cohort $589 [*P*<0.01]). The proportion of resource use for 1 year was also significantly higher (*P*<0.0001; Tables 7 and 8). Given the increased comorbid conditions for the aortic cohort (increased pulmonary disease, diabetes mellitus, hyperlipidemia, hypertension; Tables 2 and 3) relative to the matched controls, alongside their underlying aortic pathology, this difference in resource use was anticipated. Still, the margins were considerable. Of the 4 posthospitalization services that have improved physical conditioning and general health at their core (home care, rehabilitation, complex continuing care, and long-term care), the closest comparable use by the matched comparison cohort was the use of long-term care facilities (TADs 3.6%, comparison cohort 2.5% [*P*<0.0001]; TAAs 3.7%, comparison cohort 2.8% [*P*<0.0001]). For the other general health services, resource use was, respectively, 5.2 and 4.2 times more frequently used for TADs and TAAs for home care (TADs 44.4%, comparison cohort 8.5% [*P*<0.0001]; TAAs 37.7%, comparison cohort 9.0% [*P*<0.0001]); 8.5 and 5.7 times more frequently used for complex continuing care (TADs 5.1%, comparison cohort 0.6% [*P*<0.0001]; TAAs 3.4%, comparison cohort 0.6% [*P*<0.0001]); and 21 and 10 times more frequently used for rehabilitation relative to the matched comparison cohort (TADs 12.6%, comparison cohort 0.6% [*P*<0.0001]; TAAs 7.0%, comparison cohort 0.7% [*P*<0.0001]; Tables 7 and 8). Interestingly, despite the overall increased median costs and resource use of the posthospitalization healthcare services relative to the matched comparison cohort, specific to long-term care, the 1-year median costs were higher for the matched comparison cohort relative to both TAD and TAA patients (Figures 4 and 5). Conversely

**Table 7. Percentage of Posthospitalization Resource Use for TAD Patients Relative to Matched Comparison Cohort in Ontario, Canada (2003–2016)**

| | TAD | | | | | | Matched Cohort (%) | *P* Value* |
|---|---|---|---|---|---|---|---|---|
| | Stratified by Treatment (%) | | | Stratified by Type (%) | | All Dissections (%) | | |
| Post Hospitalization Resources | Surgery | TEVAR | Medical Management | Type A | Type B | Overall | | |
| Readmission, general—any admission related to initial TAD | 14.4 | 27.2 | 5.1 | 12.7 | 8.4 | 9.4 | ··· | ··· |
| Readmission for reintervention (subset from row above) | 3.2 | 6.6 | 0.0 | 3.4 | 0.8 | 1.4 | ··· | ··· |
| Rehabilitation | 18.9 | 21.4 | 8.7 | 19.0 | 10.7 | 12.6 | 0.6 | <0.0001 |
| Complex continuing care | 4.1 | 6.1 | 5.4 | 3.7 | 5.5 | 5.1 | 0.6 | <0.0001 |
| Long-term care | 2.3 | 2.0 | 4.3 | 1.8 | 4.1 | 3.6 | 2.5 | <0.0001 |
| Home care | 49.6 | 51.2 | 41.2 | 48.1 | 43.3 | 44.4 | 8.5 | <0.0001 |
| Prescription drugs (only medications listed within study design) | 58.9 | 59.8 | 60.7 | 58.1 | 60.7 | 60.1 | 36.4 | <0.0001 |
| All CT imaging | 60.5 | 83.5 | 38.1 | 59.9 | 44.2 | 48.0 | 2.4 | <0.0001 |
| All MRI imaging | 5.4 | 3.2 | 2.3 | 6.0 | 2.4 | 3.3 | 0.1 | <0.0001 |

CT indicates computed tomography; MRI, magnetic resonance imaging; TAD, thoracic aortic dissection; and TEVAR, thoracic endovascular aortic repair.
**P* values are based on McNemar's test. Comparison is between TAD "Overall" column and "Matched Controls" (matched comparison cohort).

and more in line with the overall data, complex continuing care facilities had higher 1-year median costs for TAD and TAA cases relative to the matched comparison cohort. This stark contrast in the use of these 2 extended-level assistant services, with increased expenditures for continuing care versus long-term care facilities, highlights the more apt pathway of assisted care required by the thoracic aortic population and the type of postindexed hospitalization obstacles to physical recovery that they endure.

When assessing the economic impact of home care, rehabilitation, complex care, and long-term care on the healthcare system ability to treat TADs and TAAs, both the proportion of the thoracic aortic population using the service (Tables 7 and 8) as well as the median cost of that service (Figures 4 and 5) play a role. Rehabilitation ranked first as the greatest posthospitalization cost expenditure to the healthcare system at $22.9 million (TADs $11.9 million, TAAs $11.0 million). The service was not used in excess (TADs 12.6%, TAAs, 7%), but the median cost per person was considerable (TADs $19 165, TAAs $16 059). Complex continuing care ranked second, with a cumulative cost of $12.5 million (TADs $5.3 million, TAAs $7.2 million). This service was used even less than that of rehabilitation (TADs 5.1%, TAAs 3.4%); however, the median cost per person for complex continuing care was higher (TADs $20 911, TAAs $21 737). For home care, a clear inverse relationship was identified. Home care was the most used posthospitalization general health service by a vast margin (TADs 44.4%, TAAs 37.7%; Tables 7 and 8), but the median per person cost was substantially lower relative to the other services (TADs $1868, TAAs $1648; Figures 4 and 5). This resulted in home care ranking as the third most expensive of the 4 services, with a cumulative cost of $10.2 million (TADs 4.1 million, TAAs $6.1 million). The least expensive service for the TAD and TAA population was long-term care facilities, with a cumulative cost of 9.1 million (TADs $3.1 million, TAAs $6.0 million). The need for these facilities was proportionally small (TADs 3.6%, TAAs 3.7%), but again, the median cost per person (TADs $17 691, TAAs $16 615) was fairly comparable with rehabilitation and complex continuing care services. A further breakdown of these cost expenditures into type A and type B dissection subsets is listed in Table 9.

## Health Resource Use Across Sex, Age, and Place of Residence

Notably, the proportion of healthcare resource use for TADs and TAAs did vary across sex, age, and place of residence. Whereas men showed an increase in median costs for indexed hospitalizations relative to women, as noted previously (Tables 5 and 6), women used more posthospitalization healthcare services than men and had higher median costs for select posthospitalization services. For TADs, the proportion of women using home care services (50.5% women, 40.8% men; $P<0.0001$), long-term care services (5.1% women, 2.7% men; $P<0.001$), and specific to type A aortic dissections, rehabilitation

**Table 8. Percentage of Postindexed Hospitalization Resource Use for TAA Patients Relative to a Matched Comparison Cohort in Ontario, Canada (2003–2016)**

| | TAA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Stratified by Treatment (%) | | | Stratified by Aortic Segment (%) | | | | All Aneurysms (%) | | |
| Posthospitalization Resources | Surgery | TEVAR | Medical Management | Arch TEVAR or Surgery | Ascending TEVAR or Surgery | Descending TEVAR or Surgery | Segment Not Known Medical Management | Overall | Matched Cohort (%) | *P* Value* |
| Readmission, general—any admission related to initial TAA | 22.4 | 32.9 | 5.4 | 39.3 | 20.5 | 32.5 | 5.4 | 15.1 | ··· | ··· |
| Readmission for reintervention (subset from row above) | 1.2 | 7.2 | 0.0 | 5.0 | 0.8 | 5.4 | 0.0 | 1.0 | ··· | ··· |
| Rehabilitation | 7.7 | 8.2 | 6.2 | 10.0 | 7.1 | 10.1 | 6.2 | 7.0 | 0.7 | <0.0001 |
| Complex continuing care | 1.8 | 3.8 | 5.0 | 2.7 | 1.8 | 3.0 | 5.0 | 3.4 | 0.6 | <0.0001 |
| Long-term care | 0.8 | 2.5 | 6.8 | 0.0 | 0.7 | 2.5 | 6.8 | 3.7 | 2.8 | <0.0001 |
| Home care | 32.1 | 51.5 | 41.8 | 40.6 | 29.9 | 50.3 | 41.8 | 37.7 | 9.0 | <0.0001 |
| Prescription drugs (only medications listed within study design) | 57.8 | 80.7 | 71.5 | 65.8 | 56.2 | 75.8 | 71.5 | 65.5 | 42.4 | <0.0001 |
| All CT imaging | 29.3 | 77.8 | 30.7 | 49.3 | 26.4 | 64.6 | 30.7 | 32.7 | 2.8 | <0.0001 |
| All MRI imaging | 2.3 | 0.7 | 2.0 | 3.2 | 2.2 | 1.8 | 2.0 | 2.1 | 0.1 | <0.0001 |

CT indicates computed tomography; MRI, magnetic resonance imaging; TAA, thoracic aortic aneurysm; and TEVAR, thoracic endovascular aortic repair.
**P* values are based on McNemar's test. Comparison is between TAA "Overall" column and "Matched Controls" (matched comparison cohort).

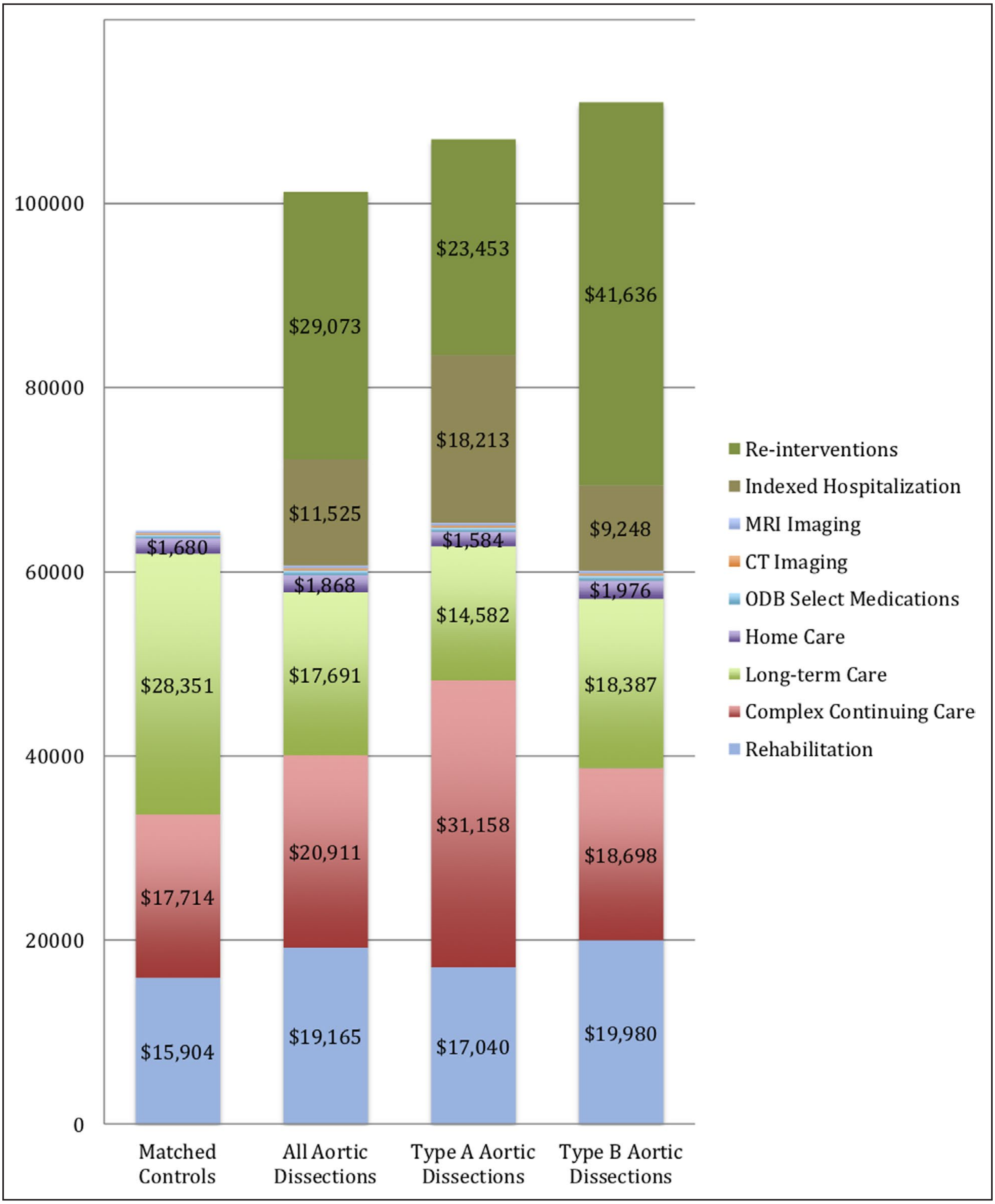


**Figure 4. Median costs for 1 year of healthcare system resource use to treat thoracic aortic dissections and matched comparisons cohort in Ontario, Canada (2003–2016; 2017 Canadian dollars). Matched controls are matched to the "All" aortic dissection cohort.**
CT indicates computed tomography; MRI, magnetic resonance imaging; and ODB, Ontario Drug Benefit Database.

services (24.8% women, 16.4% men; $P$<0.001), was significantly increased (Figure 6). Not only were these services proportionally used more but also home care ($2023 women, $1756 men) and long-term care ($20 847 women, $15 838 men) had an increased 1-year median cost for women in comparison with men.

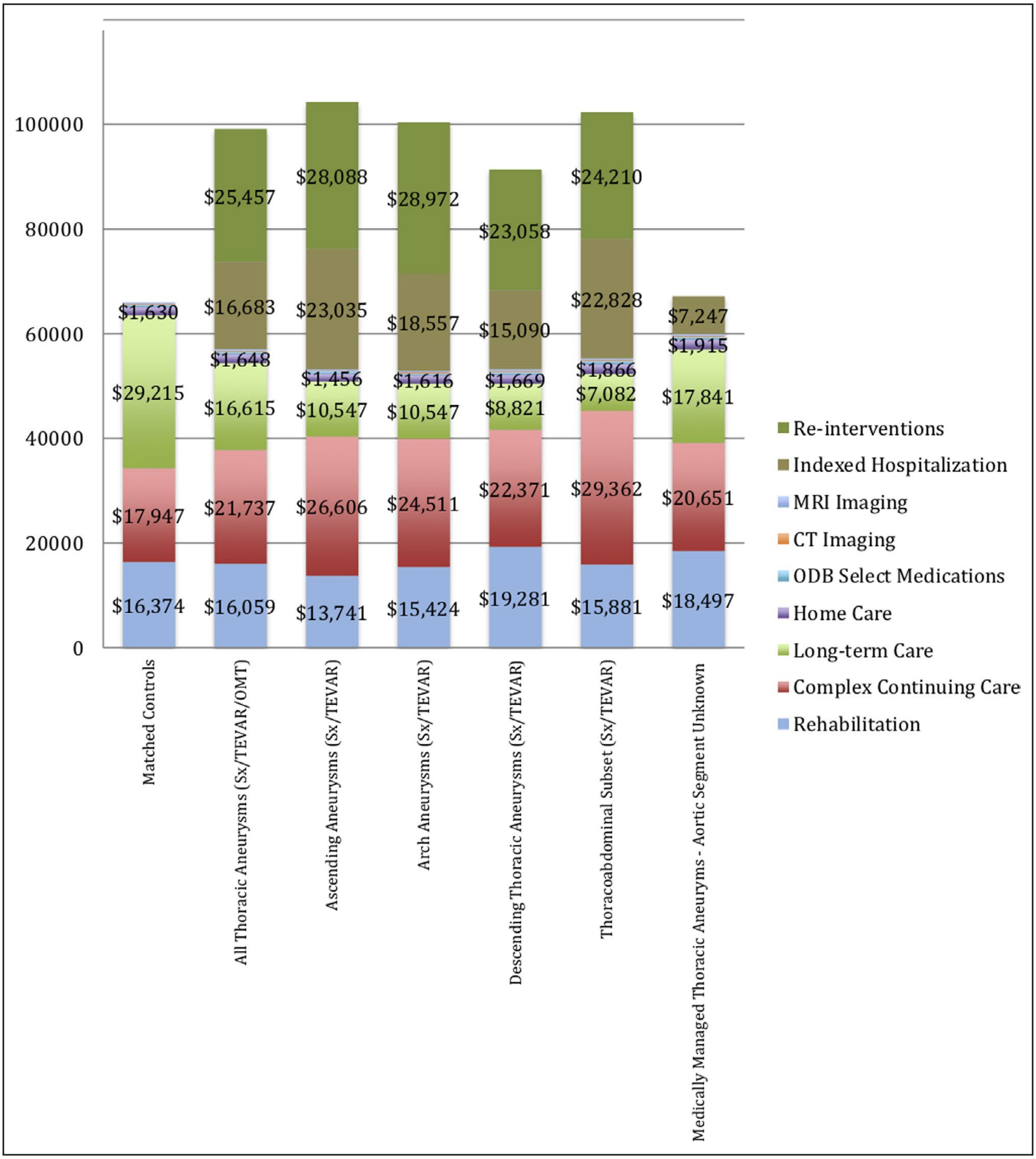


**Figure 5. Median costs for 1 year of healthcare system resource use to treat thoracic aortic aneurysms and a matched comparison cohort in Ontario, Canada (2003–2016; 2017 Canadian dollars).**
Matched controls are matched to the "All" thoracic aortic aneurysm cohort.CT indicates computed tomography; MRI, magnetic resonance imaging; ODB, Ontario Drug Benefit Database; OMT, optimal medical therapy; Sx, surgery; and TEVAR, thoracic endovascular aortic repair.

Moreover, although the rates of reinterventions were similar across the sexes (1.3% women, 1.5% men; $P$=0.289), the median 1-year costs for those inevitably requiring a reintervention was substantially higher for women ($46 281) relative to men ($25 369). Men had more computed tomography imaging by the 1-year mark than did women (50.4% men, 43.7% women; $P$<0.001), but the median costs were equivocal. For

**Table 9. One-Year Median and Cumulative Costs for Select Postindexed Hospitalization Resource Use Services After Hospital Admission for a Thoracic Aortic Dissection or Thoracic Aortic Aneurysm in Ontario, Canada (2003–2016)**

| | Thoracic Aortic Dissections | | | Thoracic Aortic Aneurysms |
|---|---|---|---|---|
| | Overall | Type A | Type B | Overall |
| 1-y median cost 2017 Canadian Dollars | | | | |
| Rehabilitation | $19 165 | $17 040 | $19 980 | $16 059 |
| Complex continuing care | $20 911 | $31 158 | $18 698 | $21 737 |
| Long-term care | $17 691 | $14 582 | $18 387 | $16 615 |
| Home care | $1868 | $1584 | $1976 | $1648 |
| 1-y cumulative cost | | | | |
| Rehabilitation | $11.9 M | $3.9 M | $8.0 M | $11.0 M |
| Complex continuing care | $5.3 M | $1.4 M | $3.9 M | $7.2 M |
| Long-term care | $3.1 M | $308 409 | $2.8 M | $6.0 M |
| Home care | $4.1 M | $895 237 | $3.2 M | $6.1 M |

M indicates million.

TAAs, the proportion of women using posthospitalization services was significantly higher relative to men in regard to rehabilitation (9.7% women, 5.7% men; *P*<0.001), complex continuing care (5.1% women, 2.5% men; *P*<0.001), long-term care (6.4% women, 2.3% men; *P*<0.001), home care (46.8% women, 33% men; *P*<0.001), and computed tomography imaging (35.4% women, 31.3% women; *P*<0.001; Figure 7). Increased 1-year median costs were again identified for women relative to men for home care ($1895 women, $1576 men), complex continuing care ($22 371 women, $20 993 men), and long-term care services ($18 685 women, $13 295 men).

With respect to age, the proportional use of the 4 posthospitalization convalescent services increased with increasing age for type A dissections (Figure 8). Type B dissections, on the other hand, had an incremental increase in use for 3 of the services; however, a “U” shaped representation was noted for rehabilitation (Figure 8). This is likely indicative of an aggressive surgical approach to younger patients balanced against the increased comorbid condition yet less aggressive management within the elderly population. The overall TAA cohort also showed increasing resource use with increasing age (Figure 9). Lastly, place of residence showed significantly more healthcare resource use for TAD and TAA patients by urban residents relative to those living in a rural setting for rehabilitation (13.6% urban, 7.1% rural; *P*<0.0001) and complex continuing care (5.4% urban, 3.2%; *P*<0.01). There was no difference for long-term care or home care services. This likely relates to disparities in access to care for select posthospital services more so than it does to differences with respect to the need for such services based on one’s place of residence.

## DISCUSSION

The vast majority of health expenditures are directed toward a small proportion of the population.[10,11] Those most in need of medical care are patients with an acute illness in the background of comorbid conditions or patients faced with the unrelenting ailments of chronic disease.[11] The aortic continuum of TADs and TAAs is unique. Although distinct entities, broader management encompasses both disease processes together and embodies both high acuity for emergent surgery or TEVAR (acute dissections) in addition to lifelong chronicity (chronic dissections and aneurysms) with surveillance imaging and potential repeat interventions. Together, TADs and TAAs are the prototypical disease entities to foment escalations in healthcare costs. Despite this, actual quantitative cost data on thoracic aortic disease, necessary to facilitate tangible initiatives toward cost containment, remain sparse.

The current study provides a comprehensive assessment into the expenditures to manage TADs and TAAs from the date of diagnosis onward through an array of healthcare services within a publicly funded healthcare system. Several key findings were identified. First, the management of TADs and TAAs are indeed costly. The healthcare system spent $587 million toward 1 year of healthcare services on 0.1% of Ontario’s 13.8 million population. Second, cost expenditures to treat thoracic aortic disease continue to escalate in an upward projection. The yearly total hospital costs for TADs and TAAs significantly increased beyond the rate of inflation. This is likely attributable to the increased incidence of disease for TADs and TAAs within the Ontario population.[6] However, total hospital costs are not the only expenditure to increase. Specific to TADs, median hospital costs have also escalated in large part attributable to increasing costs for type A dissections. Adjustments to median costs are often the result of a change in care patterns. These can manifest in various ways. It is postulated that a major influence to increased median costs for type A dissections is that more of the historically nonoperative patients (deemed palliative in years past) are being offered surgery and surviving.[6,12] Recent trend analyses for type A dissections in Ontario would support this inference, whereby despite a static operative mortality, hospital mortality demonstrably improved.[6] Surgical success in historically nonoperative patients explains

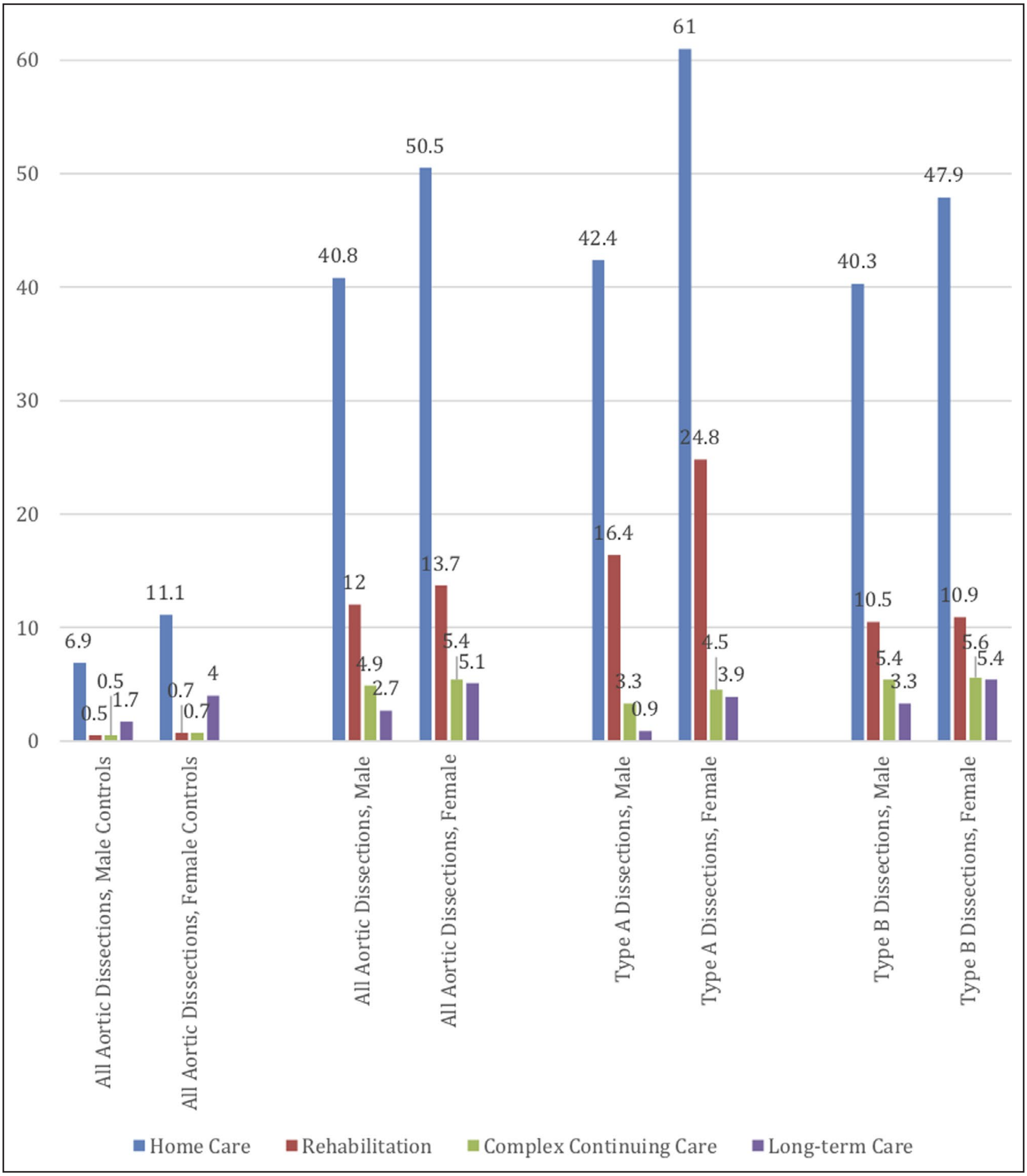


**Figure 6. Percentage of home care, rehabilitation, complex continuing care, and long-term care services by 1 year posttreatment for thoracic aortic dissections and matched comparison cohort stratified by sex in Ontario, Canada (2003–2016).** Matched controls are matched to the "All" aortic dissection cohort.

this paradox.[7] Still, despite a presumed trend toward more surgical successes in extremis patients, the percentage of patients with a type A dissection accepted for surgery remained modest in this series at 54%. Other health systems have reported similar experiences.[13,14] This reflects the time-sensitive nature of type A dissections and the need for expeditious transfer to a hospital with the expertise to treat the disease in a timely fashion immediately upon diagnosis.

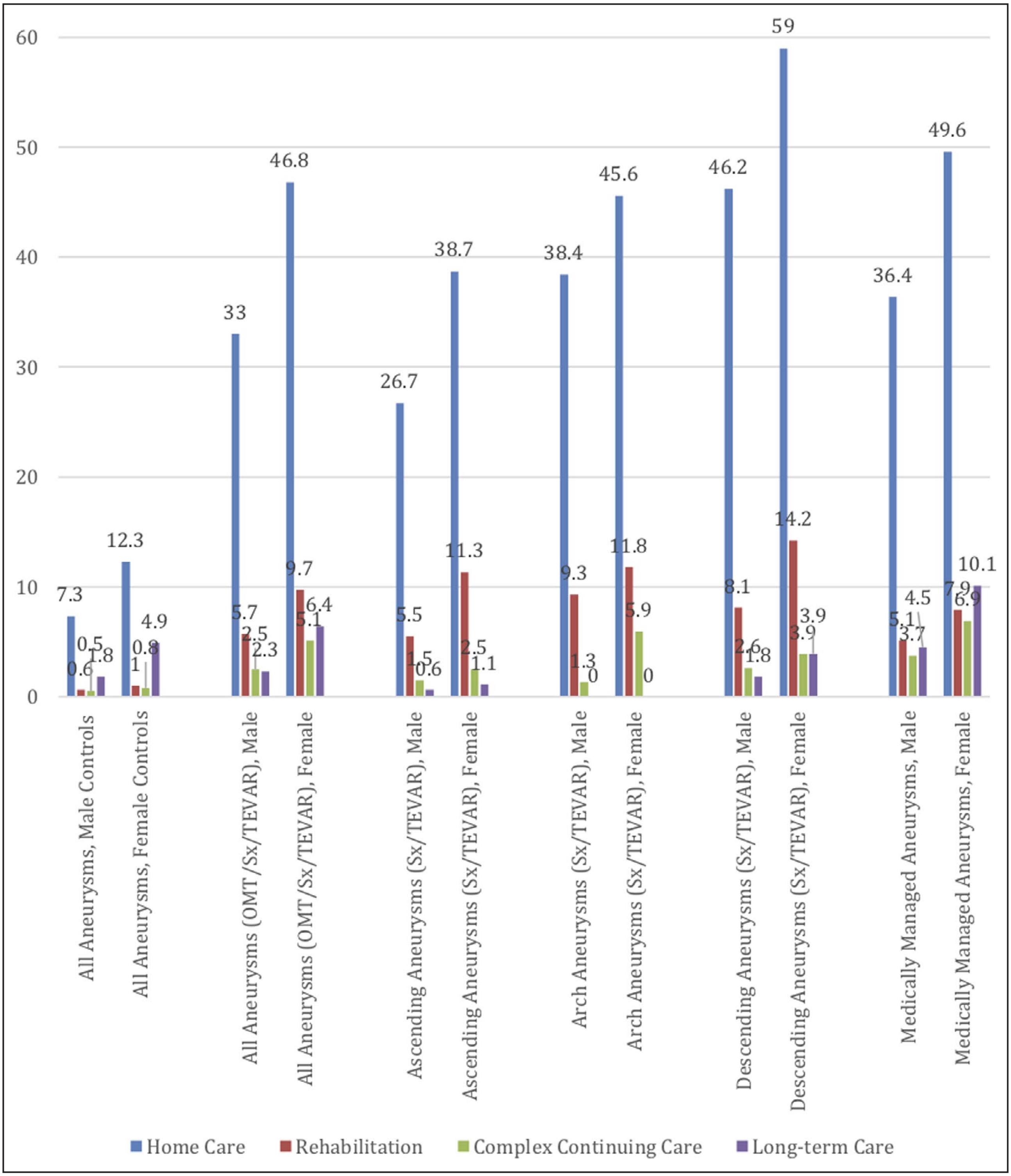


**Figure 7. Percentage of home care, rehabilitation, complex continuing care, and long-term care services by 1 year posttreatment for thoracic aortic aneurysms and a matched comparison cohort stratified by sex in Ontario, Canada (2003–2016). Matched controls are matched to the "All" thoracic aortic aneurysm cohort.**
OMT indicates optimal medical therapy; Sx, surgery; and TEVAR, thoracic endovascular aortic repair.

An increased use of TEVAR for type B dissections is another presumable influence for the increased median costs for TADs. Although median hospital costs were nonsignificant for type B dissections across the 13-year time period of the study, from 2007 onward an escalation in median costs was apparent. The 2007 time point correlates with increasing TEVAR use for type B dissections.

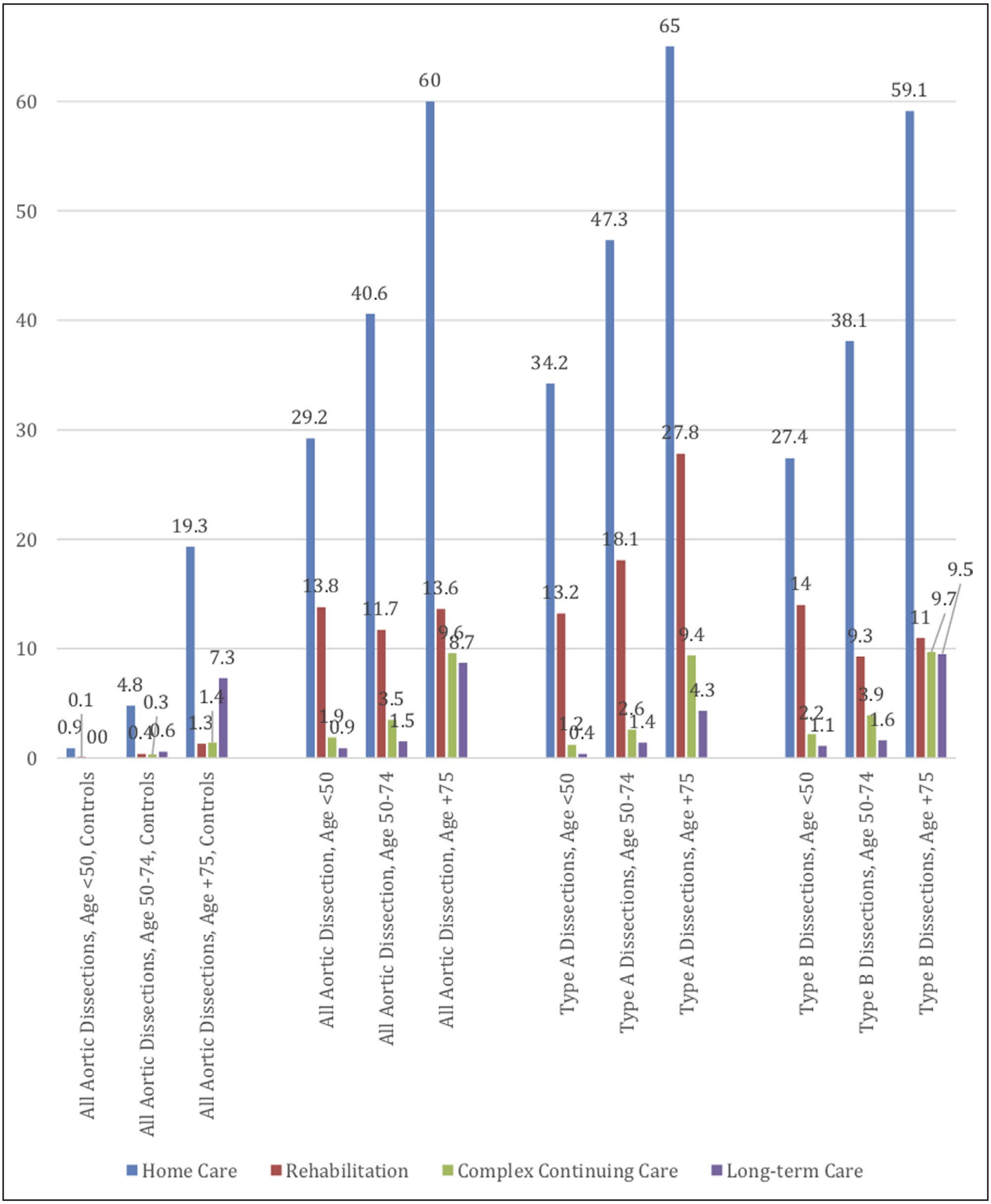


**Figure 8. Percentage of home care, rehabilitation, complex continuing care, and long-term care services by 1 year posttreatment for thoracic aortic dissections and a matched comparison cohort stratified by age in Ontario, Canada (2003–2016).**
Matched controls are matched to the "All" aortic dissection cohort.

Although speculative, these 2 shifts in patient care—(1) previously palliated type A dissections transitioned into a cohort of surgical survivors and (2) previously medically managed type B dissections transitioned toward TEVAR—are presumed to have played a large role in the observed increased median

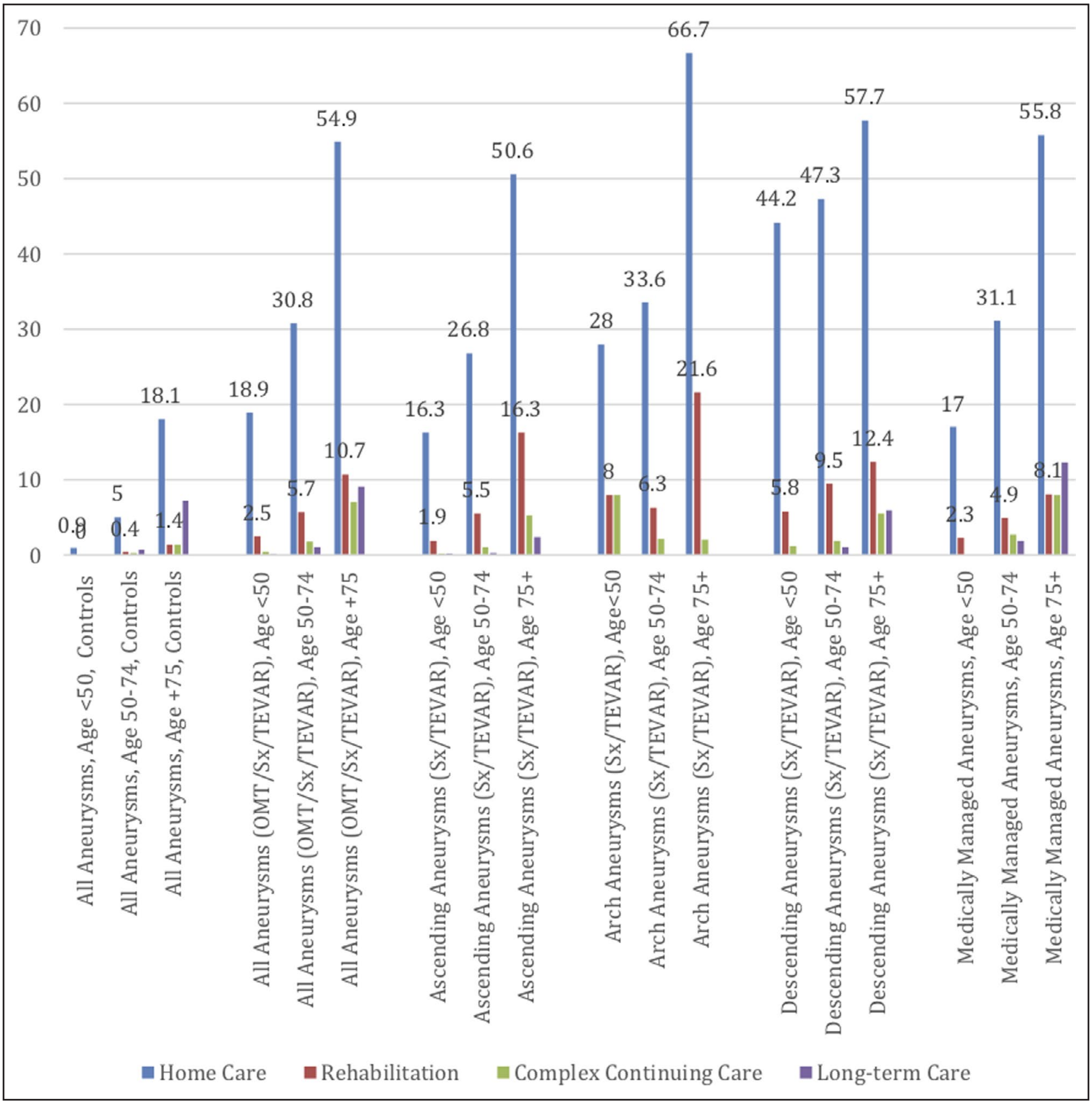


**Figure 9. Percentage of home care, rehabilitation, complex continuing care, and long-term care services by 1 year posttreatment for thoracic aortic aneurysms and a matched comparison cohort stratified by age in Ontario, Canada (2003–2016). Matched controls are matched to the "All" thoracic aortic aneurysm cohort.**
OMT indicates optimal medical therapy; Sx, surgery; and TEVAR, thoracic endovascular aortic repair.

costs. With continued efforts to better the number of successful operative repairs for type A dissections, in addition to the now broader indications for TEVAR in uncomplicated type B dissections,[15] the median costs are almost certain to continue in an upward trajectory.

Conversely, for TAAs, the median hospital costs significantly decreased. As noted previously, although various factors certainly influence such trends, some inferences can be made. One likely explanation for the decreased costs was the earlier diagnosis of TAAs secondary to increased imaging. Early diagnosis lends to a greater cohort of small aneurysms, which are below the surgical size threshold and thus treated medically. Increasing the medically treated cohort relative to TEVAR or surgery drives down the median hospital costs for the overall TAA cohort. This may cause a misleading perception of decreased cost when in actual fact it is a lower median cost spread across a greater incidence of disease for an overall greater cost the system. Improved efficiency with TEVAR and surgery over time may also have played a role.

Third, for patients with TADs and TAAs, the use and cost of posthospital healthcare resources is considerable. Home care services alone were used by 40% of the TAD and TAA patient cohort, whereas rehabilitation services equated to $22.9 million in cost expenditures. What remains unclear and warrants further investigation is how the use or disuse of these posthospitalization healthcare services impact clinical outcomes and if certain services negate the need for other services. The hospital readmission rate for the TAD and TAA cohort was 22%. Although rehabilitation services are costly, they are far less costly than hospital readmissions. Did rehabilitation use have an impact on the risk of readmission and could further engagement of rehabilitation by patients bring a net cost savings to the system? Indeed, evidence does suggest that cardiac rehabilitation programs reduce hospital readmissions.[16] These complex interlays between the various posthospital healthcare services are complex and beyond the scope of this study. However, the current study lays the groundwork to allow for further, more granular investigations in this area.

Fourth, variance in costs and resource use are evident across sex, age, and place of residence. For age and place of residence, the differences seem fairly self-explanatory. Distance appears to have an impact on access to certain healthcare services, and increasing age lends to more costly interventions. The one exception to this generalization was the increased median indexed hospitalization costs for TEVAR procedures in TAD patients younger than 50 years of age. The most likely explanation for this observation would be the higher incidence of trauma in this younger cohort, specifically high-velocity deceleration injuries from motor vehicle accidents. Trauma patients often have multiorgan impairment requiring various surgical procedures and prolonged stays in the intensive care unit. Although TEVAR was necessitated to treat a disruption or dissection of the aorta, TEVAR by itself was unlikely to be the driver of the increased hospital costs seen in this subset of patients.

For sex-specific differences, there may be more questions than answers. We have previously demonstrated that women have higher hospital mortality relative to men for TADs and TAAs in Ontario.[6] Recent studies reaffirmed these results[3] and together support prior data from the International Registry of Acute Aortic Dissections.[17] Interestingly, our study shows that this contrast between men and women does not stop at hospital outcomes. Women not only used more posthospitalization services than men but also the median costs were higher for select services. This would suggest that even within hospital survivors, there are differences between men and women that impact the need for ongoing care, with women more likely to require enhanced health support services. Presumably this is a result of both biologic[18] and sex differences[19] intermixed within the construct of societal norms. Whereas women are referred later to specialists and often have more comorbid conditions at presentation for a given cardiovascular condition,[20,21] they are also more likely to seek general medical care.[22] To the degree that the use of posthospitalization health resources by women is attributed to an increased medical need versus a more receptive attitude to such care versus men requires further study.

Finally, the current study identifies key drivers of cost for TADs and TAAs, some of which are modifiable and some that are not. An increased incidence of disease, increasingly complex surgery for high-risk patients, and increased integration of endovascular technologies into the thoracic aortic armamentarium for the betterment of patient care are largely nonmodifiable factors. Cost containment initiatives should be directed toward establishing the root cause for hospital readmissions and reinterventions as well as establishing the net positive or negative effect that posthospital resources have on the need for additional services.

## Limitations

With a base population of 13.8 million people having complete hospital records because of legislated data collection within a universal healthcare system, this is the largest economic analysis of thoracic aortic disease in the published literature. Still, despite robust data, there are certain limitations to the study. This is a retrospective analysis of administrative data sets. Although presumably negligible, a degree of misclassification is inevitable. A conservative methodology was used to capture incident cases of TAAs. The TAAs that ruptured or dissected were not "double-counted" and were analyzed solely as TADs, so the true 1-year economic burden on the healthcare system attributable to TAAs is underestimated. Moreover, the overall results are a conservative estimate of the true burden of disease, as follow-up was only for 1 year beyond the indexed hospitalization. The need for imaging surveillance and the risk of repeat interventions is lifelong for these patients, to which true burden to the system is most certainly higher than what we report. The methods employed safeguard to ensure that the vast majority of the aortic dissection cohort were acute in nature by necessitating a 5-year disease-free interlude for study inclusion. Still, a subset of chronic dissections, presumably of statistically negligible numbers, are certain to be present, lending to slight cohort heterogeneity.

## CONCLUSIONS

The current study demonstrates that total yearly costs have risen significantly for TADs and TAAs during the past decade. Median TAD hospitalization costs have also increased, whereas median TAA hospitalization costs have decreased. Women use posthospital healthcare services more often than do men. Policies to counteract escalating costs should have initiatives to reduce readmissions and reinterventions as a key focus. Examining the interconnected relationship of the various posthospital healthcare services and their individual effects on overall patient progress through the health system on route to recovery is also recommended.

## ARTICLE INFORMATION

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### Disclosures

None.

### Supplementary Materials

**Tables S1–S3**

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# SUPPLEMENTAL MATERIAL

**Table S1. Pharmacological agents assessed within cost analysis.**

Oral Lipid Lowering Agents

| **Statin Agents** | **Antilipidemics Agents** |
|---|---|
| Atorvastatin | Bezafibrate |
| Fluvastatin | Ezetimibe |
| Lovastatin | Fenofibrate |
| Pravastatin | Gemfibrozil |
| Rosuvastatin | |
| Simvastatin | |
| | |

Oral Antihypertensive Agents

| **Beta Blocker Agents** | **Diuretic Agents** | **Beta Blocker & Diuretic Combination Agents** |
|---|---|---|
| Acebutolol | Amiloride | Amiloride & Hydrochlorothiazide |
| Atenolol | Bumetanide | Atenolol & Chlorthalidone |
| Bisoprolol | Chlorthalidone | Pindolol & Hydrochlorothiazide |
| Carvedilol | Eplerenone | Propanolol & Hydrochlorothiazide |
| Labetolol | Ethacrynic Acid | Timolol & Hydrochlorothiazide |
| Metoprolol | Furosemide | |
| Nadolol | Hydrochlorothiazide | |
| Oxprenolol | Indapamide | |
| Pindolol | Metolazone | **Diuretic Combinations Agents** |
| Propanolol | Spironolactone | Hydrochlorothiazide & Spironolactone |
| Timolol | Triamterene | Hydrochlorothiazide & Triamterene |
| | | |
| **Angiotensin Converting Enzyme Inhibitor Agents** | **Angiotensin Converting Enzyme Inhibitor & Diuretic Combination Agents** | |
| Benazepril | Cilazapril & Hydrochlorothiazide | |
| Captopril | Lisinopril & Hydrochlorothiazide | |
| Cilazapril | Quinapril & Hydrochlorothiazide | |
| Enalipril | Ramipril & Hydrochlorothiazide | |
| Fisinopril | Perindopril & Indapamide | |
| Lisinopril | | |
| Perindopril | | |
| Quinapril | | |
| Ramipril | | |
| Trandolapril | | |

Oral Antihypertensive Agents

| Angiotensin II Receptor Blocker Agents | Angiotensin II Receptor Blocker & Calcium Channel Blocker Combination Agents |
|---|---|
| Candesartan | Telmisartan & Amlodipine |
| Eprosartan | |
| Irbesartan | **Angiotensin II Receptor Blocker & Diuretic Combination Agents** |
| Losartan | |
| Olmesartan | Candesartan & Hydrochlorothiazide |
| Telmisartan | Eprosartan & Hydrochlorothiazide |
| Valsartan | Irbesartan & Hydrochlorothiazide |
| | Losartan & Hydrochlorothiazide |
| **Calcium Channel Blocker Agents** | Olmesartan & Hydrochlorothiazide |
| Amlodipine | Telmisartan & Hydrochlorothiazide |
| Diltiazem | Valsartan & Hydrochlorothiazide |
| Felodipine | |
| Nefedipine | |
| Verapamil | |
| | |

Oral Lipid Lowering & Antihypertensive in Combination

| Statin & Calcium Channel Blocker Combination Agent |
|---|
| Atorvastatin & Amlodipine |

**Table S2. Cross-linked universal healthcare administrative databases and extractable data-points.**

| Name of Database | Data extractable from database |
|---|---|
| Canadian Institute for Health Information – Discharge Abstract Database (CIHI-DAD) and Same Day Surgery Database (CIHI-SDS) | Collects person's hospital admissions and discharge data along with information on diagnoses and any procedures performed |
| Continuing Care Reporting System (CCRS) | Collects demographic, clinical, functional and resource utilization information on individuals receiving continuing care services in hospitals or long-term care homes |
| Drug Identifier Number (DIN) | Codes prescription drugs to unique identifier |
| Home Care Database (HCD) | Collects clinical, administrative and resource utilization data from publicly funded home care programs |
| Local Health Integration Network (LHIN) | Collects data on socioeconomic status and geographics (rural or urban place of residence) |
| National Ambulatory Care Reporting System (NACRS) | Collects data on all hospital based and community based ambulatory care, including outpatient clinics and visits to the emergency department |
| National Rehabilitation Reporting System (NRS) | Collects data from participating adult inpatient rehabilitation facilities and programs. |
| Office of the Registrar General – Deaths database (ORGD) | Collects in-hospital deaths and cause of death. |
| Ontario Drug Benefit (ODB) | Collects drug benefit information, including recipients, payment, claims, and pharmacy and practitioner information. |
| Ontario Health Insurance Plan (OHIP) | Collects fee-for-service billing claims for inpatient and outpatient services |
| Ontario Home Care Administrative System | Collects clinical, administrative and resource utilization data from publicly funded home care programs |
| Registered Persons Database (RPDB) | Collects vital statistics on permanent residents of Ontario |
| Statistics Canada | Collects population based general statistics |

**Table S3. Diagnostic & procedural codes for thoracic aortic dissections and thoracic aortic aneurysms.**

ICD-10-CA diagnosis codes for Thoracic Aortic Dissections

| ICD-10-CA Description | ICD-10-CA Code |
|---|---|
| Dissection of aorta [any part] | I710 |
| Injury of thoracic aorta | S250 |
| Thoracic aortic aneurysm, ruptured | I71 |
| Thoracoabdominal aortic aneurysm, ruptured | I715 |
| Aneurysm and dissection of unspecified site | I729 |

ICD-10-CA: International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada

ICD-10-CA diagnosis codes for Thoracic Aortic Aneurysms

| ICD-10-CA Description | ICD-10-CA Code |
|---|---|
| Aneurysm of aorta in disease classified elsewhere (Syphilitic) | I790 |
| Thoracic aortic aneurysm, without mention of rupture | I712 |
| Thoracoabdominal aortic aneurysm, without mention of rupture | I716 |
| Aortic arch syndrome [Takayasu] | M314 |

ICD-10-CA: International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada

CCI codes for Surgical and Endovascular Procedures

| CCI Code | Description | Type of Intervention | Type of Aortic Dissection/Aneurysm |
|---|---|---|---|
| 1HV90WJCFN | Excision total with reconstruction, aortic valve, replacement of valve, aortic root and ascending aorta [e.g. Bentall] using open approach with mechanical valve and synthetic aorta | Surgery | Ascending |
| 1HV90WJXXA | Excision total with reconstruction, aortic valve, replacement of valve, aortic root and ascending aorta [e.g. Bentall] using open approach with autograft tissue valve and autograft aorta | Surgery | Ascending |
| 1HV90WJXXD | Excision total with reconstruction, aortic valve, replacement of valve, aortic root and ascending aorta | Surgery | Ascending |

| | | | |
|---|---|---|---|
| | [e.g. Bentall] using open approach with xenograft tissue valve [e.g. bovine or porcine tissue] and synthetic aorta | | |
| 1HV90WJXXK | Excision total with reconstruction, aortic valve, replacement of valve, aortic root and ascending aorta [e.g. Bentall] using open approach with homograft tissue valve and homograft aorta | Surgery | Ascending |
| 1HV90WJXXL | Excision total with reconstruction, aortic valve, replacement of valve, aortic root and ascending aorta [e.g. Bentall] using open approach with xenograft tissue valve [e.g. bovine or porcine tissue] and xenograft aorta | Surgery | Ascending |
| 1IA80GQNRN | Repair, ascending aorta using percutaneous transluminal approach and (endovascular) stent with synthetic tissue [e.g. stent graft] | Endovascular | Ascending |
| 1IA80LA | Repair, ascending aorta using open approach without tissue | Surgery | Ascending |
| 1IA80LAXXA | Repair, ascending aorta using open approach with autograft [e.g. pericardial patch, omental patch] | Surgery | Ascending |
| 1IA80LAXXK | Repair, ascending aorta using open approach with homograft [e.g. arterial homograft] | Surgery | Ascending |
| 1IA80LAXXL | Repair, ascending aorta using open approach with xenograft | Surgery | Ascending |
| 1IA80LAXXN | Repair, ascending aorta using open approach with synthetic tissue [e.g. Teflon felt, Dacron, Nylon, Orlon] | Surgery | Ascending |
| 1IA82LA | Reattachment, ascending aorta using open approach | Surgery | Ascending |
| 1IA87LA | Excision partial, ascending aorta using open approach without | Surgery | Ascending |

| | | | |
|---|---|---|---|
| | tissue [e.g. anastomosis] | | |
| 1IB80GQNRN | Repair, arch of aorta using percutaneous transluminal approach and (endovascular) stent with synthetic tissue [e.g. stent graft] | Endovascular | Arch |
| 1IB80LA | Repair, arch of aorta using open approach without tissue | Surgery | Arch |
| 1IB80LAXXA | Repair, arch of aorta using open approach with autograft [e.g. pericardial patch] | Surgery | Arch |
| 1IB80LAXXK | Repair, arch of aorta using open approach with homograft [e.g. arterial homograft] | Surgery | Arch |
| 1IB80LAXXL | Repair, arch of aorta using open approach with xenograft | Surgery | Arch |
| 1IB80LAXXN | Repair, arch of aorta using open approach with synthetic material [e.g. Teflon felt, Dacron, Nylon, Orlon] | Surgery | Arch |
| 1IC50GQOA | Dilation, thoracic [descending] aorta using percutaneous transluminal arterial approach balloon dilator with (endovascular) stent (insertion) | Endovascular | Descending |
| 1IC50GSBD | Dilation, thoracic [descending] aorta using percutaneous transluminal approach with placement/implant of stent and mechanical balloon dilator | Endovascular | Descending |
| 1IC50LANR | Dilation, thoracic [descending] aorta using endovascular stent [e.g. ⌈Z÷ stent] open approach (e.g. retroperitoneal) | Endovascular | Descending |
| 1IC55LANRA | Removal of device, thoracic [descending] aorta open approach surgical repair of defect using autograft of endovascular stent | Surgical Re-intervention | Descending |
| 1IC55LANRN | Removal of device, thoracic [descending] aorta open approach surgical repair of defect using synthetic material of endovascular stent | Surgical Re-intervention | Descending |
| 1IC55LANRQ | Removal of device, thoracic [descending] aorta open approach surgical repair of defect using combined sources of tissue of endovascular stent | Surgical Re-intervention | Descending |
| 1IC80GQNRN | Repair, thoracic [descending] | Endovascular | Descending |

| | | | |
|---|---|---|---|
| | aorta using percutaneous transluminal approach and (endovascular) stent with synthetic tissue [e.g. stent graft] | | |
| 1IC80LA | Repair, thoracic [descending] aorta using open approach without tissue | Surgery | Descending |
| 1IC80LAXXA | Repair, thoracic [descending] aorta using open approach with autograft [e.g. pericardial patch, subclavian flap] | Surgery | Descending |
| 1IC80LAXXK | Repair, thoracic [descending] aorta using open approach with homograft [e.g. arterial homograft] | Surgery | Descending |
| 1IC80LAXXL | Repair, thoracic [descending] aorta using open approach with xenograft | Surgery | Descending |
| 1IC80LAXXN | Repair, thoracic [descending] aorta using open approach with synthetic material [e.g. Teflon felt, Dacron, Nylon, Orlon] | Surgery | Descending |
| 1IC80LAXXQ | Repair, thoracic [descending] aorta using open approach with combined sources of tissue | Surgery | Descending |
| 1IC80WC | Repair, thoracic [descending] aorta using open approach with fenestration (aneurysm) technique (e.g. re-entry operation) | Surgery | Descending |
| 1IC82LA | Reattachment, thoracic [descending] aorta using open approach without tissue | Surgery | Descending |
| 1IC82LAXXA | Reattachment, thoracic [descending] aorta using open approach with autograft | Surgery | Descending |
| 1IC82LAXXN | Reattachment, thoracic [descending] aorta using open approach with synthetic material | Surgery | Descending |
| 1IC82LAXXQ | Reattachment, thoracic [descending] aorta using open approach with combined sources of tissue | Surgery | Descending |
| 1IC87LA | Excision partial, thoracic [descending] aorta using open approach with simple end-to-end anastomosis | Surgery | Descending |
| 1IC87LAXXN | Excision partial, thoracic [descending] aorta using open approach with synthetic material [e.g. Teflon felt, Dacron] | Surgery | Descending |

| | | | |
|---|---|---|---|
| 1IC87LAXXQ | Excision partial, thoracic [descending] aorta using open approach with combined sources of tissue | Surgery | Descending |
| 1IC87TQ | Excision partial, thoracic [descending] aorta using open approach with extended end-to-end anastomosis | Surgery | Descending |
| 1ID80QFXXK | Repair, aorta NEC open thoracoabdominal approach using homograft (e.g. arterial homograft) | Surgery | Descending |
| 1ID80QFXXN | Repair, aorta NEC open thoracoabdominal approach using synthetic material (e.g. Teflon, Dacron. Nylon, Orlon) | Surgery | Descending |
| 1ID80QFXXQ | Repair, aorta NEC open thoracoabdominal approach using combined sources of tissue | Surgery | Descending |
| 1ID87QFXXK | Excision partial, aorta NEC using homograft thoracoabdominal approach | Surgery | Descending |
| 1ID87QFXXN | Excision partial, aorta NEC using synthetic material thoracoabdominal approach | Surgery | Descending |
| 1ID87QFXXQ | Excision partial, aorta NEC using combined sources of tissue thoracoabdominal approach | Surgery | Descending |

CCI: Canadian Classification of Health Interventions; NEC: not elsewhere classified.