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Open Repair of Chronic Thoracic And Thoracoabdominal Aortic Dissection Using Deep Hypothermia and Circulatory Arrest

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47 ABSTRACT:

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49 Background: Chronic dissection of the thoracic and thoracoabdominal aorta as sequela of a prior
50 type A or B dissection is a challenging problem that requires close radiographic surveillance and
51 prompt operative intervention in the presence of symptoms or aneurysm formation. Open repair
52 of chronic thoracic and thoracoabdominal aortic dissection using deep hypothermia has been our
53 preferred method to treat this complex pathology. The advantages of this technique include
54 organ and spinal cord protection, the flexibility to extend the repair proximally into the arch and
55 the ability to limit ischemia to all vascular beds.

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57 Methods: Open repair of arch by left thoracotomy, descending thoracic and thoracoabdominal
58 aortic pathology using deep hypothermia was performed in 664 patients from 1995 to 2015. A
59 subset of this cohort had chronic thoracoabdominal aortic dissection (n=196). All non-emergent
60 patients had coronary angiography and echocardiography preoperatively. Significant coronary
61 artery disease or severe aortic insufficiency was addressed prior to repair of the chronic
62 dissection. In recent years, lumbar drains were placed preoperatively in the most extensive
63 repairs extents II and III). Important intercostal arteries from T8 to L1 were revascularized with
64 smaller diameter looped grafts. Multibranched grafts for the visceral segment have been
65 preferred in recent years.

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67 Results: Mean age was 58 ± 14 years. Males comprised 74% of the cohort. Aortopathy was
68 confirmed in 18% of the cohort. Prior thoracic aortic repair occurred in 57% and prior
69 abdominal aortic repair in 14%. Prior type A aortic dissection occurred in 44% and prior type B

70 in 56%. Operative mortality was 3.6%, permanent spinal cord ischemia occurred in 2.6%,
71 permanent hemodialysis in 0% and permanent stroke in 1%. Reexploration for bleeding was
72 5.1% and respiratory failure requiring tracheostomy occurred in 2.6%. Postoperative length of
73 stay was 11.9±9.7 days. Reintervention for pseudoaneurysm or growth of a distal aneurysm was
74 6.9%. One, five and ten year survival was 93%, 79% and 57%, respectively.

75
76 Conclusions: Open repair of chronic thoracic and thoracoabdominal aortic dissection using deep
77 hypothermia and circulatory arrest has low morbidity and mortality. The need for reintervention
78 is low and long-term survival is excellent. We believe that open repair continues to be the gold
79 standard in patients who are suitable candidates for surgery.

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92 Chronic dissection of the thoracic and thoracoabdominal aorta as sequela of a prior type A or B
93 dissection is a challenging problem that requires close radiographic surveillance and prompt
94 operative intervention in the presence of symptoms or aneurysm formation. Every
95 thoracoabdominal aortic dissection is unique in its combination of primary entry tear, reentry
96 tears, fenestrations, extent of aortic involvement, involvement of branch vessels, flow
97 distribution, and interplay between the true and false lumen. This complex pathology typically
98 does not lend itself to a simple surgical solution.

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100 Open repair of chronic thoracic and thoracoabdominal aortic dissection using deep hypothermia
101 has been our preferred method to treat this complex pathology. The advantages of this technique
102 include organ and spinal cord protection, the flexibility to extend the repair proximally into the
103 arch and the ability to limit ischemic injury to important vascular beds. The disadvantages
104 include longer perfusion times and limited applicability to the ruptured aneurysm. The entire
105 thoracoabdominal dissection can be addressed at once if the entire thoracoabdominal aorta is
106 aneurysmal. Alternatively, only the aneurysmal portion need be replaced with fenestration of the
107 dissection septum at the distal extent of the repair.

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109 This study highlights our experience with open repair of arch by left thoracotomy, descending
110 thoracic and thoracoabdominal aortic dissection using deep hypothermia and circulatory arrest.

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115 Methods:

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117 Institutional Review Board of Indiana University approval was obtained for the study.

118 Individual patient consent was waived. From January 1995 to December 2015, 664 patients

119 underwent open thoracic (by left thoracotomy) or thoracoabdominal aneurysm repair using deep

120 hypothermia and circulatory arrest. The technique has been described elsewhere [1,2]. Briefly,

121 anesthetic technique is composed of total intravenous anesthesia using propofol and remifentanyl

122 to allow preservation of motor-evoked and somatosensory-evoked potentials for spinal cord

123 monitoring. Placement of a double-lumen endotracheal tube (Covidien Mallinckrodt

124 Endobronchial tube, left, Medtronic, Inc., Minneapolis, MN)) or single lumen tube with a

125 bronchial blocker (Arndt Endobronchial Blocker Set, Cook Medical Inc., Bloomington, IN) is

126 used for selective airway control. Transcranial infrared oxygen sensors are placed on the left and

127 right forehead (INVOS Cerebral/Somatic Oximeter, Somenetics Corporation, Troy, MI). Motor-

128 evoked and somatosensory-evoked potentials (Cadwell Cascade stimulator-detector, disposable

129 subdermal needle electrodes, Cadwell Laboratories, Inc, Kennewick, WA) are recorded after

130 induction of anesthesia for baseline values and are assessed intraoperatively after separation from

131 cardiopulmonary bypass.

132

133 The patient is placed on full cardiopulmonary bypass typically through the left common femoral

134 artery and vein. The arterial inflow temperature is reduced to achieve 15 degrees Centigrade.

135 Once the heart fibrillates, decompression of the left ventricle is performed by placing a drainage

136 catheter (Covidien Argyle, ventricular sump catheter, Medtronic, Inc., Minneapolis, MN)

137 through the left ventricular apex to low active suction. Once the patient has been cooled for 30

138 minutes with an arterial blood temperature of less than 20 degrees Centigrade, circulatory arrest
139 is performed. The left ventricular sump catheter is turned off, the venous line is clamped and
140 arterial flow is stopped. A cross clamp is placed distal to the proposed proximal anastomosis on
141 the descending thoracic aorta. Hypothermic low flow (1 to 1.5 L/min) is started to the lower
142 body while the proximal anastomosis is performed. If the entire transverse arch is to be replaced,
143 perfusion catheters (Gundry Silicone RCSP cannula, Medtronic, Inc., Minneapolis, MN) are
144 placed in the innominate and left common carotid arteries for bilateral selective antegrade
145 cerebral perfusion at 10 mL/kg/min. After the arch is reconstructed or the proximal anastomosis
146 performed, perfusion is restored to the upper body (1 to 1.5L/min) and the repair progresses step-
147 wise proximally to distally. Intercostal arteries, three to four levels, from T8 to L1 are
148 revascularized. When the abdominal aortic segment is opened, perfusion catheters (9F Pruitt
149 Irrigation Occlusion Catheter, LeMaitre Vascular, Inc. Burlington, MA) are placed into the
150 orifices of the visceral vessels and low flow hypothermic blood perfusion is instituted at 200 to
151 300 mL/min. After reconstruction of the abdominal visceral segment is completed and the
152 abdominal viscera reperfused, rewarming can commence with commensurate increases in
153 cardiopulmonary bypass flow. Finally, the distal anastomosis is performed at the infrarenal aorta
154 at the bifurcation or prior abdominal aortic graft. If the common iliac arteries are aneurysmal,
155 iliac artery reconstructions are also performed.

156
157 As the patient is being rewarmed, the heart is defibrillated when the arterial inflow temperature is
158 above 30 degrees Centigrade. Once rewarmed to tympanic and bladder temperatures above 35
159 degrees Centigrade, the patient is weaned from cardiopulmonary bypass. Vasopressor support is
160 used to achieve a mean arterial pressure of 70-90 mmHg. If motor evoked potentials are not

161 present in the bilateral lower extremities, the mean pressure is elevated to 90-110 mmHg and a
162 lumbar drain is placed prior to leaving the operating room if it was not placed at the beginning of
163 the procedure. Immediate postoperative hemoglobin is maintained above 8 mg/dL.

164

165 Recent technical changes in our surgical strategy for repair of all pathologies of thoracic and
166 thoracoabdominal aneurysm has included the addition of arterial cannulation sites in the
167 ascending aorta, distal aortic arch, proximal descending aorta, left or right common carotid
168 arteries to effort to avoid retrograde flow in the thoracoabdominal aorta. However, the vast
169 majority (188/196) of the patients with chronic dissection had common femoral arterial
170 cannulation for cardiopulmonary bypass. We have also championed the use of branched surgical
171 grafts or smaller diameter grafts to reconstruct the abdominal visceral arteries. Additionally,
172 revascularization of intercostal arteries is now performed using a small diameter looped bypass
173 graft [3]. It is our thought, that the use of smaller diameter grafts will reduce the likelihood of
174 visceral or intercostal patch pseudoaneurysm.

175

176 Of 664 patients who had thoracic (by left thoracotomy) or thoracoabdominal aortic aneurysm
177 repair, 196 patients, who comprise the current study, had chronic thoracoabdominal aortic
178 dissection from prior type A or B dissection. Indications for repair included an overall maximal
179 size of the aneurysmal aorta to be at least 50 to 55 mm in diameter or rapid growth of the aorta at
180 a rate greater than or equal to 5 mm per year by computed tomographic imaging (and since 2012
181 with center-line reconstruction). Patients with a known or suspected connective tissue disorder
182 or a known familial aortopathy were repaired at a thoracic aortic diameter of 50 mm, whereas
183 those without connective tissue disorder or familial aortopathy were repaired at a thoracic aortic

184 diameter of 55 mm. An abdominal aortic component of 50 mm in the setting of a chronic
185 thoracoabdominal aortic dissection was also an indication for surgery. Other indications include
186 persistent and difficult to control hypertension (one patient), chronic mesenteric ischemia (three
187 patients), intractable pain (two patients) and a left common iliac artery aneurysm of 38 mm (one
188 patient).

189
190 All patients with elective operations had coronary angiography and echocardiography prior to
191 aortic repair. Significant flow-limiting coronary stenosis was addressed prior to aneurysm repair
192 with percutaneous coronary intervention or coronary artery bypass (sometimes performed
193 concomitantly with aneurysm repair, n=6/196). Severe aortic valve insufficiency required either
194 aortic valve repair or replacement prior to repair of the chronic dissection.

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196
197 Finally in 2013, we began preoperatively placing cerebrospinal fluid drains in our most extensive
198 repairs, Crawford extents II and III, and in those patients who will have thoracoabdominal repair
199 joining with a prior abdominal aortic graft or thoracic aortic graft. The reason for this change in
200 technique was the increased number of paraplegia and paraparesis in patients with de novo
201 extensive repairs (extents II or III) or completion thoracoabdominal replacement after prior aortic
202 repair. A lumbar drain is not placed preoperatively in patients taking non-aspirin antiplatelet
203 agents or oral anticoagulation or if there is a mycotic aneurysm or systemic infection or if the
204 operation is emergent.

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206

207 Statistical Analysis

208 The study is retrospective. Continuous variables are represented as the mean with the standard
209 deviation and/or or median with interquartile range as necessary. Categorical variables are
210 represented as the number and percentage of the cohort. The Social Security Death Index, the
211 Indiana Health Information Exchange and the electronic medical record of our institution were
212 used to identify patients who have died during the study period. Follow up data were
213 retrospectively collected and the last known follow up was recorded. Analysis of survival was
214 performed using the method of Kaplan and Meier. The Kaplan-Meier estimates of survivor
215 function and corresponding 95% confidence interval were calculated and plotted. The statistical
216 software package used was called R: A Language and Environment for Statistical Computing, R
217 Foundation for Statistical Computing, Vienna Austria. (<http://www.R-project.org/>).

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219

220 Results:

221

222 Preoperative patient characteristics are listed in Table 1. The mean age was 58 ± 14 years. Males
223 comprised 74% of the cohort. Patients with known connective tissue disorder (confirmed
224 Marfan syndrome, Loeys-Dietz syndrome or familial aortopathy) comprised 18% of the cohort.
225 Other comorbid disease is found in Table 1. Chronic thoracoabdominal aortic dissection after
226 prior repair of a Type A aortic dissection occurred in 44%. Chronic thoracoabdominal aortic
227 dissection as a result of a type B aortic dissection occurred in 56%. Prior thoracic aortic
228 procedures occurred in 57% of patients, prior abdominal aortic procedures in 14%.

229

230 The preoperative size of the thoracic or thoracoabdominal aorta was 57.2 ± 11.0 mm (median 55
231 mm, interquartile range 10 mm). Twenty percent of patients had rapid growth (greater than 5
232 mm increase in size within a 12 month period with an aortic diameter less than 50 mm) as an
233 indication for repair.

234

235 The extent of aortic replacement is found in Table 2. Aortic replacement including total arch
236 (proximal anastomosis to the ascending aorta) or partial arch (proximal anastomosis between the
237 innominate and left subclavian arteries) in combination with the descending thoracic aorta
238 comprised 13% of the cohort. Descending thoracic aortic replacement alone (proximal
239 anastomosis distal to the left subclavian artery) occurred in 9%. A Crawford extent I
240 thoracoabdominal aortic aneurysm repair occurred in 31%. Repair that extended through the
241 visceral abdominal aorta was needed in nearly 50% of patients; 35% had extent II repair, 9%
242 extent III and 3% extent IV. Aorto-iliac or aorto-femoral reconstruction was performed in 7%.
243 The mean circulatory arrest time to the cerebrum was 24.7 ± 9.1 minutes and the mean
244 cardiopulmonary bypass time was 290.5 ± 94.6 minutes.

245

246 The operative outcomes are listed in Table 3. Overall operative mortality was 3.6%.
247 Neurological deficit occurred in 3%, but only 1% had permanent deficits. Spinal cord ischemia
248 occurred in 11 patients, but only 5 patients (2.6%) suffered permanent paraplegia or paraparesis.

249

250 The number of patients who had segmental artery reimplantation was 104 (53%). The need for
251 segmental artery reimplantation was related to the extent of repair: extent I 39 of 61 patients
252 (64%), extent II 53 of 69 patients (77%), extent III 8 of 17 patients (47%), extent IV 2 of 5

253 patients (40%), and descending with or without arch replacement 2 of 44 patients (5%). The
254 number of patients with spinal cord ischemia who had intercostal reimplantation was 8 (7.7%).
255 The number of patients with spinal cord ischemia who did not have intercostal artery
256 reimplantation was 3 (3.3%, $p=0.22$ vs. patients with intercostal reimplantation, Fisher's exact
257 test).

258

259 We placed lumbar drains preoperatively in only 15 patients (since 2013 when our use of
260 preoperative spinal drains began for those with the highest risk of spinal cord ischemia). Of
261 these, only 2 had transient paralysis or paraparesis and no patient had permanent motor deficit.
262 Lumbar drains were placed in a total of 36 patients (18.4%) either pre or postoperatively and up
263 to 30 days postoperatively. Ten of 36 experienced transient (6) or permanent (4) spinal cord
264 ischemia. Only one patient (0.6%) who did not receive a spinal drain had permanent paralysis.

265

266 Acute renal failure was a postoperative complication in 5.1%, any hemodialysis was needed in
267 4.1%. However, no patients who survived the procedure required permanent hemodialysis.

268 Postoperative pneumonia occurred in 15% of patients. Only 2.6% of patients required
269 tracheostomy. Analysis of major complications and mortality according to the extent of aortic
270 repair is found in Table 3A.

271 Reexploration for postoperative hemorrhage was needed in 10 patients (5%). Mean
272 postoperative length of stay of survivors ($n=189/196$) was 11.9 ± 9.7 days. Blood product
273 utilization for the index hospitalization is listed in Table 4. The median blood product
274 administration for the hospitalization was 4 units (interquartile range 13 units).

275

276 Follow up after surgery for distal chronic aortic dissection occurs at one month after discharge
277 from the hospital and at 12 months postoperatively with computed tomographic imaging.
278 Subsequent imaging occurs at 30 months and 54 months postoperatively. Imaging can occur at
279 more frequent intervals depending upon aneurysm change or growth or the development of
280 symptoms. Of the operative survivors, 186 out of 189 (98%) had at least one follow up visit.
281 Mean follow up for our series was 46.9 ± 47.4 months (median follow up 30.9 months,
282 interquartile range 59 months). Reintervention was uncommon. Two patients required
283 reoperation for infected aortic grafts. Pseudoaneurysm of either a visceral or intercostal island
284 anastomosis occurred in 6 patients (3.1%). Reoperation for growth of a distal aneurysm was
285 performed in 7 patients (3.6%).

286

287 Figure 1 shows the long-term survival of the cohort using Kaplan-Meier analysis including 95%
288 confidence intervals and number of patients at risk. The one, three, five and ten year survival
289 was 93%, 86%, 79% and 57%, respectively. Median survival was 10.7 years.

290

291 Discussion:

292

293 Open repair of chronic distal thoracic and thoracoabdominal aortic dissection has very good
294 operative outcomes and long-term survival [4-8]. The technique of deep hypothermia and
295 circulatory arrest has low mortality and a low complication rate in thoracic and
296 thoracoabdominal aneurysm repair as seen in our series and other series by Kouchoukos [1,2,9-
297 11]. In the current study, mortality for operative repair of chronic distal aortic dissection was *not*
298 associated with a greater extent of repair or the need for arch replacement. The reason for this is

299 not clear, however hypothermia is imperative in arch replacement and is likely protective against
300 mortality in other extensive repairs. There was more spinal cord ischemia and renal failure in the
301 type II repair cohort, as would be expected in these patients with the most extensive repair,
302 however there was no statistically significant difference compared to lesser extents of repair.
303 Deep hypothermia may be able to equalize mortality across all extents of repair, including arch
304 repair. Deep hypothermia may ameliorate major complications from the most extensive and
305 complex thoracoabdominal repairs, however there were too few events in this series to make
306 meaningful statistical comparisons. Our clinical impression is that the most extensive repairs
307 (extent II and III thoracoabdominal repairs) carry the highest risk of major complication
308 including spinal cord ischemia and renal failure.

309
310 One reported potentially catastrophic disadvantage of the technique of deep hypothermia for
311 thoracic and thoracoabdominal aneurysm repair is parenchymal lung hemorrhage requiring lung
312 resection. In separate series by Coselli et al and Safi et al, they reported high mortality rates and
313 hemorrhagic lung complications and advocated against routine use of deep hypothermia [12,13].
314 We had one patient who required lung resection for intractable parenchymal hemorrhage and this
315 patient did not survive. Adequate decompression of the left ventricle and pulmonary vascular
316 bed during the period of hypothermic fibrillation and minimizing the manipulation of the lung
317 during the period of anticoagulation help to avoid this potentially fatal complication. Although
318 mild parenchymal contusion is not infrequent, it did not prolong ventilation times nor increase
319 the risk of respiratory failure requiring tracheostomy in our series since we are vigilant in
320 ensuring that the left ventricle is adequately decompressed.

321

322 The perfusion strategy using deep hypothermia in the repair of chronic distal aortic dissection
323 may have the best surgical outcomes compared to other perfusion strategies [2,6]. The
324 advantages of full cardiopulmonary bypass and deep hypothermia include organ protection
325 including the spinal cord and kidneys, the ability to extend the repair proximally into the arch as
326 needed and the limitation of ischemia to important vascular beds [9-11]. Protection of the spinal
327 cord with the combination of hypothermia and aggressive intercostal reimplantation provides
328 low rates of permanent paralysis. We believe that the addition of preoperative spinal drains in
329 our most extensive repairs can lower our paraplegia rate even further as seen in our most recent
330 extensive repairs after 2013 with no permanent spinal cord deficit.
331

332 Perfusion times are certainly longer with the technique of deep hypothermia, but we have not
333 encountered significant postoperative bleeding and coagulopathy as evidenced by our low rate of
334 reexplorations for bleeding and low need for blood product transfusion. Other surgical
335 techniques using left heart bypass cannot address arch pathology proximal to the left subclavian
336 artery. Organ protection can be suboptimal with periods of warm ischemia or hypoperfusion to
337 various vascular beds. Historical series of open repair of chronic distal aortic dissection using
338 normothermic techniques report mortality of 10-15% [14,15]. Mortality using left heart bypass
339 techniques is 8.6% in a contemporary series, however in this series, repair was limited to the
340 descending thoracic aorta [8]. Other contemporary series describe mortality 5.8% to 9.6% using
341 a variety of perfusion techniques, including deep hypothermia and circulatory arrest in a minority
342 of patients [4-6]. Although it is difficult to directly compare perfusion strategies, our series
343 compares favorably to these while including complex arch and aorto-iliac repairs. Deep
344 hypothermia and circulatory arrest has been our preferred technique to repair thoracoabdominal

345 aortic aneurysms of all extents and in particular chronic thoracic and thoracoabdominal aortic
346 dissection.

347

348 Open repair of chronic thoracic and thoracoabdominal aortic dissection using deep hypothermia
349 for the suitable operative candidate has low morbidity and mortality. The average age of our
350 cohort was 58 years. This young age reflects our patient population with denovo type B aortic
351 dissection, prior type A dissection, familial aortopathy and connective tissue disorders. Those
352 with connective tissue disorders and familial aortopathy comprise nearly 20% of our cohort. The
353 mean age of those without known connective tissue disorder or known familial aortopathy was
354 61 ± 12 years, reflecting the relatively young patient with aortic dissection in Indiana.

355

356 We intervened on distal chronic aortic dissection when the thoracic aorta was 55 mm in patients
357 without known aortopathy and 50 mm with known or suspected aortopathy. We also intervened
358 on chronic thoracoabdominal dissection when the abdominal aorta was 50 mm. Kim et al stated
359 that the risk of an aortic event of an unrepaired descending or thoracoabdominal aneurysm
360 ranges from 5.5% to 8.0% in aortic diameters as small as 50 mm, 7.2% to 11.2% at aortic
361 diameter 55 mm and 9.3% to 15.6% at aortic diameter 60 mm [16]. We believe that size-for-
362 size, chronic dissection is a more lethal problem than degenerative atherosclerotic aneurysm and
363 have chosen to be more aggressive in repairing them especially given our excellent surgical
364 outcomes. Although repairing a smaller aneurysm may be technically easier and therefore may
365 have a decreased risk of mortality, the size of the aneurysm did not correlate with an increased
366 risk of mortality in our series. In fact, there was no mortality in those who had aneurysms 65
367 mm or greater (19% of the cohort).

368

369 Long-term survival is very good in our study. The ten-year survival is nearly 60%. The need for
370 reintervention is low; very low for infected surgical grafts and surprisingly low for aneurysm
371 formation of the distal aorta. Although it may be possible that our patients were cared for at
372 other institutions for complications of the repair or for distal aneurysm formation, we believe this
373 number to be low since we are the only institution in Indiana who performs these procedures to a
374 great extent.

375

376 The limitations of this study are those that are inherent to an observational, single center
377 retrospective review. The outcomes in this study may not be generalizable as the operations
378 described are predominantly performed by 2 surgeons (JW and JC) at one tertiary care hospital.
379 Our analysis of survival using the institutional medical record, the Indiana Health Information
380 Exchange data set and the Social Security Death Index (which is an incomplete data set) is
381 limited by the frequency and completeness of follow up of our patient population. The last
382 known follow up date or date of death was used in the survival analysis with the consequence of
383 a significant number of censored patients.

384

385 There is a great interest in using endovascular techniques in the treatment of chronic distal aortic
386 dissection. Endovascular repair of chronic thoracoabdominal aortic dissection can be
387 accomplished with low morbidity and mortality and usually is able to affect false lumen
388 thrombosis and aortic remodeling at the level of the endograft in the thoracic aorta [17-20].
389 However, aortic remodeling is uncommon in the abdominal aorta and reintervention *is* common
390 [20]. The currently available thoracic endografts are limited in its application to complex

391 thoracoabdominal aortic dissection with multiple visceral arteries coming off the false lumen,
392 multiple fenestrations and severely compressed true lumen. Additionally, the use of thoracic
393 endografts in connective tissue disorders may not be prudent. The long-term outcomes and
394 durability of thoracic endograft repair for chronic distal aortic dissection are not known. In open
395 repair, aortic remodeling is never in question, reintervention is rare, and success is not limited by
396 complex anatomy. The durability of open repair is excellent. The mortality and morbidity of
397 this series compares admirably with that of endograft series of chronic distal aortic dissection,
398 but with markedly less reintervention and proven long-term survival.

399

400 Open and endovascular repair should not be competing modalities. Rather, they should be
401 complementary. For the young or otherwise suitable operative candidate, open repair should
402 remain the gold standard. Ideally, all patients with connective tissue disorders should have open
403 repair as well. However, for the patient with advanced age and multiple comorbidities making
404 them a poor surgical candidate, endovascular repair may be the procedure of choice if the
405 anatomy of the aorta is favorable. As the technology for endovascular devices advances and
406 branched and/or fenestrated thoracoabdominal systems become widely available, the paradigm
407 for open versus endovascular repair will likely change.

408

409

410

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413

414 References:

415

- 416 1. Fehrenbacher JW, Siderys H, Terry C, et al. Early and late results of descending
417 thoracic and thoracoabdominal aneurysm open repair using deep hypothermia and
418 circulatory arrest. *J Thorac Cardiovasc Surg* 2010;140:S154-60.
- 419 2. Corvera JS, Fehrenbacher JW. Open repair of chronic aortic dissection using deep
420 hypothermia and circulatory arrest. *Ann Thorac Surg* 2012;94:78-83.
- 421 3. Woo EY, Mcgarvey M, Jackson BM, et al. Spinal cord ischemia may be reduced via a
422 novel technique of intercostal artery revascularization during open thoracoabdominal
423 aneurysm repair. *J Vasc Surg* 2007;46:421-6.
- 424 4. Zoli S, Etz CD, Roder F, et al. Long-Term survival after open repair of chronic distal
425 aortic dissection. *Ann Thorac Surg* 2010;89:1458-66.
- 426 5. Pujara AC, Roselli EE, Hernandez AV, et al. Open repair of chronic distal aortic
427 dissection in the endovascular era: Implications for disease management. *J Thorac*
428 *Cardiovasc Surg* 2012;144:866-73.
- 429 6. Conway AM, Sadek M, Lugo J, et al. Outcomes of open surgical repair for chronic type
430 B aortic dissections. *J Vasc Surg* 2014;59:1217-23.
- 431 7. Van Bogerijen GHW, Patel HJ, Williams DM, et al. Propensity adjusted analysis of open
432 and endovascular thoracic aortic repair for chronic type B dissection: A twenty-year
433 evaluation. *Ann Thorac Surg* 2015;99:1260-66.
- 434 8. Estrera AL, Jan A, Sandhu H, et al. Outcomes of open repair for chronic descending
435 thoracic aortic dissection. *Ann Thorac Surg* 2015;99:786-94.

- 436 9. Kulik A, Castner CF, Kouchoukos NT. Outcomes after thoracoabdominal aortic
437 aneurysm repair with hypothermic circulatory arrest. *J Thorac Cardiovasc Surg*
438 2011;141(4):953-60
- 439 10. Kouchoukos NT, Masetti P, Murphy SF. Hypothermic cardiopulmonary bypass and
440 circulatory arrest in the management of extensive thoracic and thoracoabdominal aortic
441 aneurysms. *Semin Thorac Cardiovasc Surg* 2003;15:333-9.
- 442 11. Fehrenbacher JW, Hart DW, Huddleston E, et al. Optimal end-organ protection for
443 thoracic and thoracoabdominal aneurysm repair using deep hypothermic circulatory
444 arrest. *Ann Thorac Surg* 2007;83:1041-46.
- 445 12. Safi HJ, Miller CC, Subramaniam MH et al. Thoracic and thoracoabdominal aneurysm
446 repair using cardiopulmonary bypass, profound hypothermia and circulatory arrest via
447 left side of chest incision. *J Vasc Surg* 1998;28:591-8.
- 448 13. Coselli JS, Bozinovski J, Cheung C. Hypothermic Circulatory Arrest: Safety and
449 Efficacy in the Operative Treatment of Descending Thoracic and Thoracoabdominal
450 Aortic Aneurysms. *Ann Thorac Surg* 2008;85:956-64.
- 451 14. Fann JI, Smith JA, Miller DC, et al. Surgical management of aortic dissection during a
452 30-year period. *Circulation* 1995;92:III113-21.
- 453 15. Safi HJ, Miller CC, 3rd, Reardon MJ, et al. Operation for acute and chronic aortic
454 dissection: recent outcome with regard to neurologic deficit and early death. *Ann Thorac*
455 *Surg* 1998;66:402-11.
- 456 16. Kim JB, Kim K, Lindsay ME et al. Risk of Rupture or Dissection in Descending
457 Thoracic Aortic Aneurysm. *Circulation* 2015; 132(17):1620-9.

- 458 17. The VIRTUE registry investigators. The VIRTUE registry of type B thoracic dissections
459 – study design and early results. *Eur J Vasc Endovasc Surg* 2001;41:159-66.
- 460 18. Parsa CJ, Williams JB, Bhattacharya SD, et al. Midterm results with thoracic
461 endovascular aortic repair for chronic type B aortic dissection with associated aneurysm.
462 *J Thorac Cardiovasc Surg* 2011;141:322-7.
- 463 19. Xu SD, Huang FJ, Yang JF et al. Early and midterm results of thoracic endovascular
464 aortic repair of chronic type B aortic dissection. *J Thorac Cardiovasc Surg*
465 2010;139:1548-53.
- 466 20. Leshnower BG, Szeto WY, Pochettino A, et al. Thoracic endografting reduces morbidity
467 and remodels the thoracic aorta in DeBakey III aneurysms. *Ann Thorac Surg*
468 2013;95:914-21.

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472 Legends:

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475 Central Picture Legend:

476 Completed repair of a chronic thoracoabdominal aortic dissection and aneurysm

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478 Figure Legend:

479 Figure 1. Kaplan-Meier Survivor Function with 95% confidence intervals and number at risk at
480 3 year intervals.

481 Video Legend:

482 Open Repair of a Thoracoabdominal Aortic Aneurysm Using Deep Hypothermia and Circulatory

483 Arrest

484

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	n=196	
Age (years)	57.6±13.8	
Male	145	(74.0)
Marfan syndrome	23	(11.7)
Loeys-Dietz syndrome	2	(1.0)
Familial aortopathy	10	(5.1)
Prior CABG/PCI	44	(22.4)
Hypertension	174	(88.8)
Chronic Obstructive Pulmonary Disease	27	(13.8)
Hyperlipidemia	90	(45.9)
Diabetes Mellitus	23	(11.7)
Chronic Kidney Disease	41	(20.9)
Prior Abdominal Aortic Procedure	28	(14.3)
Prior Thoracic Aortic Procedure	112	(57.1)
Prior Type A Aortic dissection	87	(44.4)
Prior Type B Aortic dissection	109	(55.6)

Table 1. Patient Characteristics. Age is represented as mean ± standard deviation. Values in parenthesis represent percentages.

	n=196	
Descending Thoracic Aorta	44	(22.4)
Descending only	18	(9.2)
Partial arch + descending	15	(7.7)
Total arch + descending	11	(5.6)
Crawford Extent I	61	(31.1)
Crawford Extent II	69	(35.2)
Crawford Extent III	17	(8.7)
Crawford Extent IV	5	(2.6)

Table 2. Extent of Aortic Replacement. Values in parenthesis represent percentages.

	n=196	
Operative Mortality	7	(3.6)
Permanent Stroke	2	(1.0)
Transient Neurological Deficit	4	(2.0)
Permanent Paraplegia/Paraparesis	5	(2.6)
Transient Spinal Cord Ischemia	6	(3.1)
Acute Renal Failure (STS definition)	10	(5.1)
Any Hemodialysis	8	(4.1)
Permanent Hemodialysis	0	(0)
Respiratory Failure, Tracheostomy	5	(2.6)
Pneumonia	29	(14.8)
Reexploration for Bleeding	10	(5.1)
Postoperative Length of Stay (days)	11.9±9.7	

Table 3. Operative Results. Postoperative length of stay is represented as mean ± standard deviation. Values in parenthesis represent percentages.

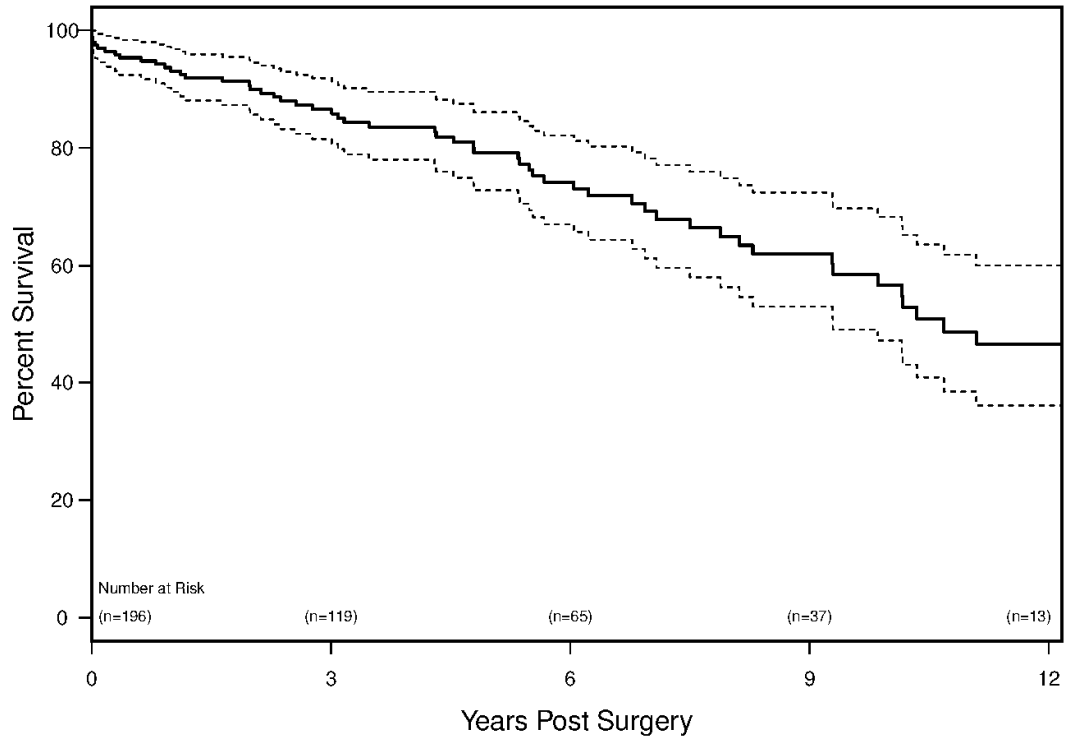
	Desc only (n=18)	Partial arch + desc (n=15)	Total arch + desc (n=11)	Extent I (n=61)	Extent II (n=69)	Extent III (n=17)	Extent IV (n=5)
Mortality	2 (11.1)	1 (6.7)	0 (0)	1 (1.6)	2 (2.9)	1 (5.9)	0 (0)
Paralysis/paraparesis	1 (5.6)	0 (0)	0 (0)	1 (1.6)	7 (10.1)	2 (11.8)	0 (0)
Permanent	1 (5.6)	0 (0)	0 (0)	0 (0)	2 (2.9)	2 (11.8)	0 (0)
Temporary	0 (0)	0 (0)	0 (0)	1 (1.6)	5 (7.2)	0 (0)	0 (0)
Acute renal failure	2 (11.1)	0 (0)	0 (0)	0 (0)	7 (10.1)	1 (5.9)	0 (0)
Any hemodialysis	2 (11.1)	0 (0)	0 (0)	0 (0)	5 (7.2)	1 (5.9)	0 (0)
Stroke	0 (0)	0 (0)	0 (0)	0 (0)	2 (2.9)	0 (0)	0 (0)
Tracheostomy	1 (5.6)	1 (6.7)	1 (9.1)	0 (0)	2 (2.9)	0 (0)	0 (0)

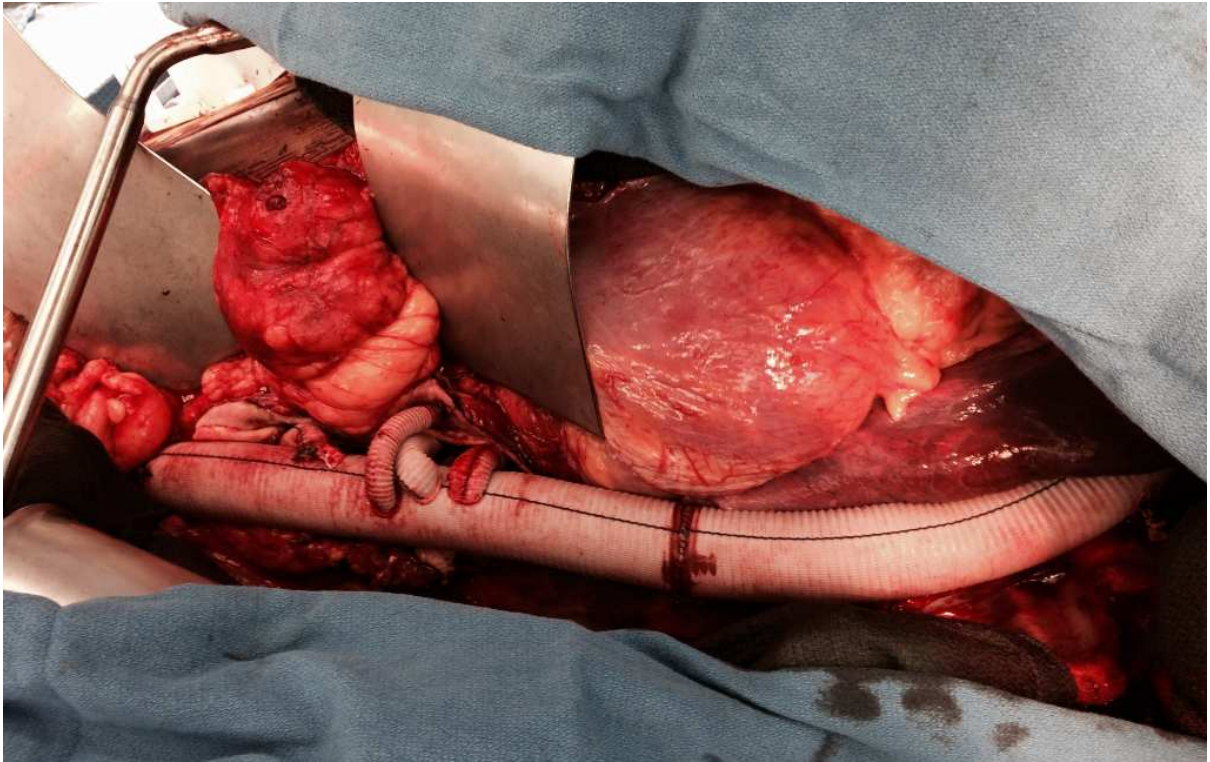
Table 3A. Major complications and mortality by extent of aortic repair. Values in parenthesis represent percentages.

	Mean	Median	25th %ile	75th %ile
Packed Red Blood Cells (units)	4.8±6.1	3	1	6
Fresh Frozen Plasma (units)	2.1±3.0	0	0	4
Platelet Pheresis (units)	1.2±1.5	1	0	2
Cryoprecipitate (10 units)	0.9±1.6	0	0	2

Table 4. Blood product utilization for the hospitalization.

Survival Post Surgery





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