

Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Short paper

First experience with the abdominal aortic and junctional tourniquet in prehospital traumatic cardiac arrest

Fay Balian^{a,b}, Alan A. Garner^{c,d,*}, Andrew Weatherall^{a,e,f}, Anna Lee^g

^a CareFlight NSW, Redbank Rd, Westmead, NSW 2145, Australia

^b Royal Prince Alfred Hospital, Sydney, Australia

^c Trauma Department, Nepean Hospital, Derby St, Kingswood, NSW 2747, Australia

^d University of Sydney, Australia

^e Division of Child and Adolescent Health, The University of Sydney, Australia

^f The Children's Hospital at Westmead, Australia

^g Department of Anaesthesia and Intensive Care, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong, China

Abstract

Introduction: The Abdominal Aortic and Junctional Tourniquet (AAJT) increased systemic vascular resistance, mean arterial pressure, carotid blood flow and rate of return of spontaneous circulation (ROSC) in animals with hypovolaemic traumatic cardiac arrest (TCA). The objective of this study was to report the first experience of the use of the AAJT as part of a pre-hospital TCA algorithm.

Methods: This is a descriptive case series of the use of the AAJT in patients with TCA in a civilian physician-led pre-hospital trauma service in Sydney, Australia between June 2015 to August 2019. Cases were identified and data sourced from routinely collected data sets within the retrieval service.

Results: During the study, 44 TCAs were attended, 22 with AAJT application. Mean time (standard deviation) to AAJT application since last signs of life was 16 (9) min. Eighteen (16 males, 2 females) patients, with median age (interquartile range) of 40 (25–58) years, were included for analysis. Seventeen patients (94%) had blunt trauma. Sixteen patients (89%) were in TCA at the time of service contact, 11 (61%) had a change in electrical activity, 4 (22%) had ROSC, and of the 6 with documented end-tidal carbon dioxide, the mean rise was 24.0 mmHg (95% CI 12.6–35.4) ($P = 0.003$). Three patients (17%) had sustained ROSC on arrival to the Emergency Department. No patients survived to hospital discharge.

Conclusion: Physiological changes were demonstrated but there were no survivors. Further research focusing on faster application times may be associated with improved outcomes.

Keywords: Traumatic cardiac arrest, Abdominal aortic and junctional tourniquet, Prehospital

Introduction

Pre-hospital resuscitation of traumatic cardiac arrest (TCA) is focused on the reversible causes: haemorrhage, hypoxia, hypovolaemia, tamponade and tension pneumothorax.^{1,2} Haemorrhage remains the

leading potentially preventable cause of death, particularly non-compressible torso haemorrhage.

Thoracic aortic clamping/compression via thoracotomy is an established intervention in TCA management.^{1,2} Manual external compression of the aorta for hypovolaemic arrest has been described in pre-hospital practice, but is difficult to maintain during transport.³

* Corresponding author at: Trauma Department, Nepean Hospital, Derby St, Kingswood, NSW 2747, Australia.

E-mail addresses: fay.balian@careflight.org (F. Balian), alan.garner@careflight.org (A.A. Garner), andrew.weatherall@careflight.org (A. Weatherall)

<https://doi.org/10.1016/j.resuscitation.2020.09.018>

Received 6 May 2020; Received in revised form 22 August 2020; Accepted 4 September 2020

Available online xxx

0300-9572/© 2020 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/>)

The Abdominal Aortic and Junctional Tourniquet (AAJT) (Compression Works LLC, Birmingham, AL, United States) provides external aortic compression. It is a belt-like device with an inflatable bladder that when applied to the abdomen at the level of the umbilicus delivers sufficient external pressure to the distal aorta to cease flow through the femoral arteries,⁴ requires minimal training, takes 60–90 s to apply,⁵ and has been shown in animal models to increase systemic vascular resistance, Mean Arterial Pressure (MAP), carotid blood flow, and increase the rate of return of spontaneous circulation (ROSC) in hypovolaemic TCA.^{6–8} There is only one previously reported case of use of the AAJT in TCA; a pulseless combat casualty in Afghanistan with return of palpable pulse and increase in end tidal carbon dioxide (etCO₂) in the setting of lower limb exsanguination⁹.

The AAJT was incorporated into the TCA algorithm of a physician staffed helicopter emergency medical service (PS-HEMS) servicing greater Sydney, Australia in June 2015. The aim of this study was to report our experience of 18 applications for civilian pre-hospital TCA and describe the barriers to AAJT application.

Methods

The report was approved by the Sydney Childrens Hospital Network Human Research Ethics Committee (2019/ETH13314).

Setting

Sydney, Australia, has a population of 5.23 million people and land area of 1.27 million hectares.¹⁰ The CareFlight Rapid Response Helicopter (CRRH) is based near the demographic centre of Sydney. Clinical crewing consists of a critical care doctor and paramedic. Dispatch is via a non-flight paramedic in a central control room

identifying cases from the NSW Ambulance Computer Assisted Dispatch system.¹¹

TCA management by the CRRH

CRRH manage TCA according to the “HOTTT drill” algorithm – (eAppendix 1). The drill addresses oxygenation via airway management (usually intubation) and ventilation, external haemorrhage control, tension pneumothorax via thoracostomy, and hypovolaemia via transfusion, with an option for resuscitative thoracotomy for tamponade. This is similar to other established algorithms for TCA used worldwide.^{1,2,12,13} In 2015, the AAJT was added to provide the third “T” in the HOTTT drill. Physicians can elect to omit AAJT application at their clinical discretion.

Subjects and eligibility criteria

This is a retrospective case series of all adult patients (age > 16 years) in TCA on whom the AAJT was applied, from June 2015 to August 2019. In cases where the AAJT was not applied as part of the HOTTT drill, the reasons were documented.

Data collection

Data was collected from the contemporaneously completed patient record and the CareFlight clinical database. Standardised forms (“CareBundles”) are also completed for every HOTTT drill (eAppendix 1), and/or the AAJT application (eAppendix 2). Cases were identified through the completed AAJT and HOTTT CareBundles. Patients with AAJT application but without a completed CareBundle were excluded from analysis due to missing data. The rest of the standard clinical record was reviewed to complete patient

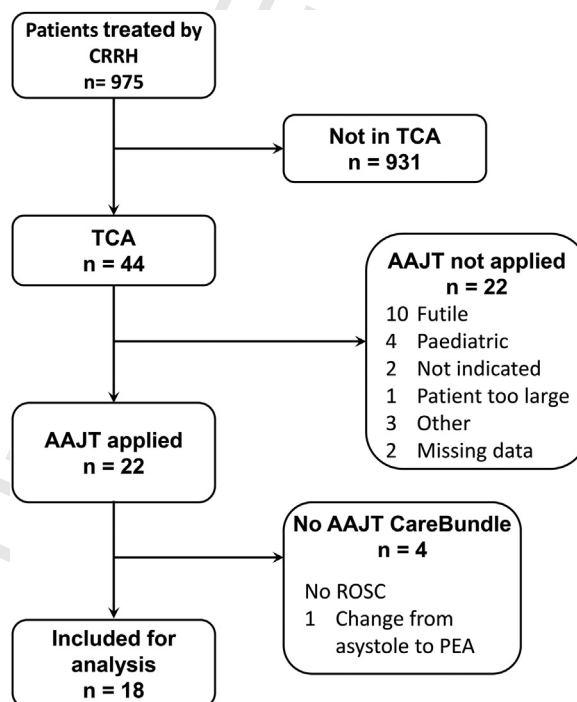


Fig. 1 – Patient flow chart of patient selection process and outcomes of patients with AAJT applied in TCA (CRRH = CareFlight Rapid Response Helicopter; AAJT = Abdominal Aortic Junctional Tourniquet; TCA = Traumatic Cardiac Arrest).

Table 1 – Characteristics of patients who underwent AAJT application.

Patient	Age (years)/ Gender	Est. weight Kg	Mechanism of injury	Time FKS to patient contact (mins)	In TCA on arrival of CRRH	Time since signs of life to application (mins)	Cardiac rhythm pre- application	First rhythm post application	ETCO ₂ change mmHg	Volume replacement	ROSC	ROSC on arrival to ED	Place deceased
1	46 M	80	MVA driver	37	Yes	8	PEA	VF/VT	.	HTS 250mls PRBCs 2 units Crystalloid 500mls	No	N/A	Scene
2	23 F	70	Pedestrian vs. vehicle	15	No	5	PEA	PEA	.	PRBCs 2 units Crystalloid 500mls	No	No	ED
3	55 M	65	Fall <5m	22	Yes	12	Asystole	PEA	.	HTS 250mLs Crystalloid 1L	Yes	Yes	ICU
4	40 M	120	MBA	23	Yes	22	Asystole	PEA	.	HTS 250mls Crystalloid 500mls	No	N/A	Scene
5	25 M	70	MVA driver	22	Yes	25	PEA	PEA	+37	PRBC 2 units Crystalloid 500mls	Yes	Yes	ICU
6	28 M	70	MVA driver	33	Yes	10	Asystole	Sinus	.	1 unit PRBC Crystalloid 500mls	Yes	N/A	Scene
7	20 M	75	MVA passenger	23	Yes	.	Asystole	Sinus	+31	PRBC 2 units	Yes	N/A	Ambulance
8	31 M	70	MBA	28	Yes	27	Asystole	PEA	+17	PRBC 1 unit	No	N/A	Scene
9	85 M	85	Pedestrian vs. vehicle	23	Yes	20	PEA	PEA	.	Crystalloid 500mls	No	N/A	Scene
10	45 M	60	Fall >5m	18	Yes	15	Asystole	.	.	Crystalloid 1L	No	N/A	Scene
11	57 M	80	MVA driver	23	Yes	5	Missing	Missing	.	Crystalloid 500mls	No	N/A	Scene
12	29 M	75	MBA	15	Yes	30	PEA	Sinus	.	HTS 250mls PRBC 2 units Plasma 2 units	Yes	Yes	ICU
13	39 M	80	MVA driver	.	Yes	20	Asystole	Asystole	.	HTS 500mLs	No	N/A	Scene
14	20 M	70	Penetrating injury to neck	27	No	1	Missing	Asystole	.	PRBC 2 unit Plasma 2 unit	No	No	ED
15	60 M	75	Pedestrian vs. vehicle	.	Yes	25	Asystole	PEA	.	HTS 250mls PRBC 1 unit Plasma 1 unit	No	N/A	Scene
16	80 M	85	Pedestrian vs. vehicle	21	Yes	10	PEA	PEA	+20	HTS 250mls PRBC 1 unit Plasma 2 units	No	N/A	Scene
17	73 F	45	MVA driver	16	Yes	22	Asystole	PEA	+31	HTS 250mls	No	N/A	Scene
18	22 M	70	MBA	17	Yes	19	Asystole	PEA	+8	PRBC 2 units Plasma 2 units	No	No	ED
Summary			Blunt 17 Penetrating 1	Mean (SD) 22.7 (6.2)	16 in TCA	Mean (SD) 16.2 (8.7)		Asystole 2 PEA 10	Mean (95% CI) 24.0 (12.6)		Yes 5 No 13		Scene 11 Ambulance

(continued on next page)

Table 1 (continued)

Patient	Age (years)/ Gender	Est. weight Kg	Mechanism of injury	Time FKS to patient contact (mins)	In TCA on arrival of CRRH	Time since signs of life to application (mins)	Cardiac rhythm pre- application	First rhythm post application	ETCO ₂ change mmHg	Volume replacement	ROSC on arrival to ED	Place deceased
	16 M/2 F Median (IQR) age 39.5 (24.5–57.8)	Median (IQR) 72.5 (70.0 –80.0)			Asystole 10 PEA 6 Missing 2	Sinus 3 VF/VT 1 Missing 2	–35.4) (P = 0.003)	Yes 3 No 3 N/A 12	1 ED 3 ICU 3			

*. =missing data; MBA = motorbike rider; MVA = motor vehicle accident; M = male; F = female; FKS = first keystroke of emergency call; TCA = traumatic cardiac arrest; CRRH = CareFlight Rapid Response Helicopter; ROSC = return of spontaneous circulation; PRBC = Packed Red Blood Cells, HTS = 7.5% Saline, Crystalloid = isotonic crystalloid, N/A: patient not transported to the Emergency Department. Age and estimated weight presented as median (IQR). Times are presented as mean (standard deviation). etCO₂ presented as mean (95% Confidence Interval).

demographic data, mechanism of injury, response times including the times of first emergency call, patient contact time, and outcome of the patient.

Data analysis

Data was checked for normality using Shapiro–Wilk’s test. Values are reported as mean and standard deviation (SD) or median and interquartile range (IQR) as appropriate. Complete case analysis was performed. Comparison of time from first keystroke to task with and without AAJT was assessed using Mann–Whitney *U* test. Before and after changes in SBP and HR associated with AAJT application were compared using Wilcoxon signed rank test. Change in ETCO₂ was assessed using one-sample *t*-test and reported as mean (95% CI). Level of significance was set at $P < 0.05$. Statistical analysis was performed using SPSS 26 (IBM Corporation, Armonk, NY).

Results

There were 975 patient contacts during the study period, of which 44 were in TCA. The AAJT was applied in 22 of these cases with Carebundle data available for analysis in 18 (Fig. 1, Table 1). Of the 22 cases where the AAJT was applied, 18 (81%) were in arrest on contact by the CRRH team. All applications were abdominal.

Six patients had pre and post application etCO₂ levels recorded and all demonstrated a clinically significant rise in etCO₂ level post application (Table 1). Two of these six cases had ROSC. One other ROSC case re-arrested after removal of the device in the ED and further resuscitation was unsuccessful. One ROSC case proceeded to organ donation.

All 18 patients had GCS 3 before and after AAJT application. Fourteen patients had no SBP before and after AAJT application (Fig. 2A). One patient had a palpable carotid pulse but the systolic blood pressure was not recorded (not shown). Overall, there was little or no difference in SBP associated with AAJT application ($P = 0.29$). Ten patients had no HR before and after AAJT application. Two patient’s HR decreased and six patients HR increased after AAJT application (Fig. 2B). Overall, there was little or no difference in HR associated with AAJT application ($P = 0.21$).

Limitations to use of the AAJT

AAJT application was not attempted in five cases where the patient was either too small (paediatric cases) or too large (Fig. 1). Non-application due to futility was due to obvious death or extended arrest time. When application was attempted, it was noted on one occasion that the device “did not fit properly” in a 65 kg patient. Other comments included “Balloon herniated inferiorly” and “AAJT malfunctioned? valve issue”.

Discussion

Our TCA study cohort was similar to those previously described in the trauma literature, predominantly blunt trauma (94%) in men (89%), average age 42.2 years.^{14,15} All applications of the AAJT were abdominal with 55% in asystole. We observed a change in electrical activity in 11 of the 17 applications (61%) with documented pre-application rhythm. In all six cases with documented pre- and post-

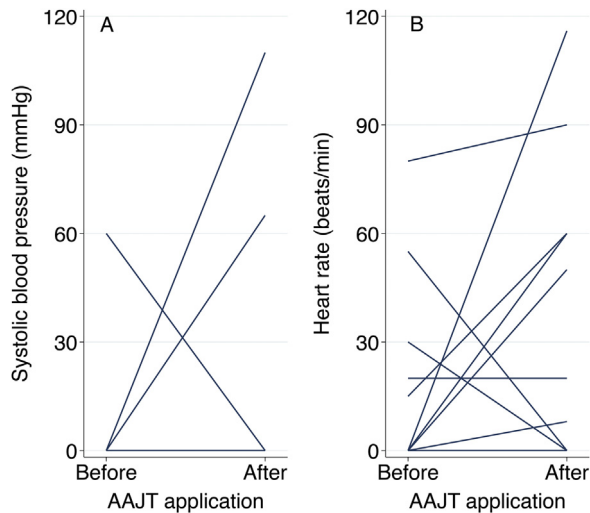


Fig. 2 – (A) Change in systolic blood pressure in 17 patients. Fourteen patients had unrecordable blood pressure before and after application, and hence are represented by the line along the baseline. (B) Change in heart rate in 18 patients.

application etCO₂, there was a clinically significant etCO₂ rise (mean 24 mmHg). These physiological changes are consistent with observations in animal studies, and suggest that perfusion to the lungs and coronary arteries is improved when the AAJT is used within a TCA algorithm.⁶ Our series cannot however be compared to the published prehospital Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) series¹⁶ as none of those patients were in TCA. The AAJT is a more practical and rapid intervention than REBOA in most patients with difficulties in AAJT application mostly due to sizing. The AAJT is inexpensive and rapidly applied so financial and logistical concerns are not a barrier to utilisation.

Mean time from clinical arrest to AAJT application was 16 min in our series. Use of any technique 16 min after TCA onset due to traumatic hypovolaemia is likely to have a very low chance of success. One patient with sustained ROSC proceeded to organ donation, which arguably is a positive outcome, despite the lack of survivors overall. As with REBOA, application prior to arrest is likely to yield the best outcomes. Earlier application may produce higher rates of ROSC than we observed. An alternate strategy of equipping ground EMS with the AAJT would also improve application times and possibly outcomes.

Although there was a low rate of ROSC and no survivors observed in our series compared with other recent reports of TCA, the AAJT was only applied in patients in whom the reversible TCA causes of hypoxia, tension pneumothorax, and pericardial tamponade had already been excluded. In TCA we use the AAJT as a damage-control strategy, in conjunction with addressing reversible causes, including blood product resuscitation, to increase rates of ROSC, bridge a gap to definitive care, and potentially increase survival rate. Whilst the AAJT has potential physiological consequences of prolonged application, it can be applied rapidly and would rarely delay transport to a trauma centre, whilst delivering equivalent aortic occlusion to zone 3 REBOA with a similar physiological profile.⁵ Brannstrom and colleagues demonstrated that transition from AAJT to zone 3 REBOA is possible,¹⁷ and adoption of both strategies would enable pre-hospital

teams to minimise scene and transport time by applying the AAJT, with trauma centres transitioning to REBOA in ED or the OT. In our system the use of prehospital REBOA should also be explored but the greatest benefit is likely to arise from decreasing the time to intervention in exsanguinating patients by adopting more effective, evidence-based dispatch strategies.¹⁸

There are several limitations in our study. There is a small number of patients and no control group. The physiological changes observed cannot be attributed exclusively to the AAJT and may be the result of other components of the TCA algorithm. Patient condition on arrival of local EMS crew was not documented, though vital signs present on EMS arrival is a positive predictor of outcome.¹⁹ We do not have details of patient injuries in most cases as post mortem results were not available, which limits our ability to determine if any deaths were potentially preventable or amenable to AAJT application, or assess potential harms from AAJT application. Hence it is suggested that the device be used within settings with strong governance oversight including follow-up for adverse effects, and ideally within a clinical trial.

Conclusions

We report the abdominal application of the AAJT in 18 prehospital TCA patients after exclusion of hypoxia, tension pneumothorax and pericardial tamponade and have demonstrated changes in physiology consistent with those seen in animal models, but no survivors. The AAJT was rapid and easy to apply in most patients. It is possible that shorter time intervals between arrest and device application may produce better outcomes and should be the focus of further studies.

Funding/support

No external funding was received to support this study.

Conflicts of interest

None.

Acknowledgements

Nil.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.resuscitation.2020.09.018>.

REFERENCES

1. Truhlár A, Deakin CD, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2015. Section 4. Cardiac arrest in special circumstances. Resuscitation 2015;95:148–201, doi:<http://dx.doi.org/10.1016/j.resuscitation.2015.07.017>.

2. Australian and New Zealand Committee on Resuscitation. Management of cardiac arrest due to trauma — Australian Resuscitation Council. ANZCOR Guidel 11101. . p. 1–11.
3. Paix BR, Tingey DJ, Copley G, et al. Prehospital external aortic compression for temporizing exsanguinating sub-diaphragmatic hemorrhage — a promising technique, but with challenges: four illustrative cases, including two survivors. *Prehosp Disaster Med* 2019;10–3, doi:<http://dx.doi.org/10.1017/S1049023X19005235>.
4. Lyon M, Johnson D, Gordon R. Use of a novel abdominal aortic and junctional tourniquet to reduce or eliminate flow in the brachial and popliteal arteries in human subjects. *Prehospital Emerg Care* 2015;19:405–8, doi:<http://dx.doi.org/10.3109/10903127.2014.980479>.
5. Rall JM, Redman TT, Ross EM, Morrison JJ, Maddry JK. Comparison of zone 3 resuscitative endovascular balloon occlusion of the aorta and the abdominal aortic and junctional tourniquet in a model of junctional hemorrhage in swine. *J Surg Res* 2018;226:31–9, doi:<http://dx.doi.org/10.1016/j.jss.2017.12.039>.
6. Rall J, Cox JM, Maddry J. The use of the abdominal aortic and junctional tourniquet during cardiopulmonary resuscitation following traumatic cardiac arrest in swine. *Mil Med* 2017;182:e2001–5, doi:<http://dx.doi.org/10.7205/MILMED-D-16-00409>.
7. Brännström A, Rocksén D, Hartman J, et al. Abdominal aortic and junctional tourniquet release after 240 min is survivable and associated with small intestine and liver ischemia after porcine class II hemorrhage. *J Trauma Acute Care Surg* 2018;1, doi:<http://dx.doi.org/10.1097/TA.0000000000002013>.
8. Rall JM, Ross JD, Clemens MS, Cox JM, Buckley TA, Morrison JJ. Hemodynamic effects of the abdominal aortic and junctional tourniquet in a hemorrhagic swine model. *J Surg Res* 2017;212:159–66, doi:<http://dx.doi.org/10.1016/j.jss.2017.01.020>.
9. Anonymous. Abdominal aortic tourniquet™ use in Afghanistan. *J Spec Oper Med* 2013;13.
10. Australian Bureau of Statistics G of A. Greater Sydney: Region Data Summary.
11. Garner AA, Lee A, Weatherall A, Langcake M, Balogh ZJ. Physician staffed helicopter emergency medical service case identification — a before and after study in children. *Scand J Trauma Resusc Emerg Med* 2016;24:1–7, doi:<http://dx.doi.org/10.1186/s13049-016-0284-6>.
12. Lockey DJ, Lyon RM, Davies GE. Development of a simple algorithm to guide the effective management of traumatic cardiac arrest. *Resuscitation* 2013;84:738–42, doi:<http://dx.doi.org/10.1016/j.resuscitation.2012.12.003>.
13. Sherren P, Reid C, Habig K, Burns BJ. Algorithm for the resuscitation of traumatic cardiac arrest patients in a physician-staffed helicopter emergency medical service. *Crit Care* 2013;17:308, doi:<http://dx.doi.org/10.1186/cc12504>.
14. Beck B, Tohira H, Bray JE, et al. Trends in traumatic out-of-hospital cardiac arrest in Perth, Western Australia from 1997 to 2014. *Resuscitation* 2016;98:79–84, doi:<http://dx.doi.org/10.1016/j.resuscitation.2015.10.015>.
15. Deasy C, Bray J, Smith K, et al. Traumatic out-of-hospital cardiac arrests in Melbourne, Australia. *Resuscitation* 2012;83:465–70, doi:<http://dx.doi.org/10.1016/j.resuscitation.2011.09.025>.
16. Lendrum R, Perkins Z, Chana M, et al. Pre-hospital Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for exsanguinating pelvic haemorrhage. *Resuscitation* 2019;135:6–13, doi:<http://dx.doi.org/10.1016/j.resuscitation.2018.12.018>.
17. Brännström A, Dahlquist A, Gustavsson J, Arborelius UP, Günther M. Transition from abdominal aortic and junctional tourniquet to zone 3 resuscitative endovascular balloon occlusion of the aorta is feasible with hemodynamic support after porcine class IV hemorrhage. *J Trauma Acute Care Surg* 2019;87:849–55, doi:<http://dx.doi.org/10.1097/TA.0000000000002426>.
18. Garner A. Pre-hospital and retrieval medicine clinical governance in Sydney and the inconvenient truth. *Emerg Med Australas* 2017;29:604–5, doi:<http://dx.doi.org/10.1111/1742-6723.12807>.
19. Evans CCD, Petersen A, Meier EN, et al. Prehospital traumatic cardiac arrest: Management and outcomes from the resuscitation outcomes consortium epistery-trauma and PROPHET registries. *J Trauma Acute Care Surg* 2016;81:285–93, doi:<http://dx.doi.org/10.1097/TA.0000000000001070>.