Procedure Complexity and Utilization Distributions for Interventional CT

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Presentation outline

- Background/Motivation
- Procedure Complexity
- Previous Studies on Interventional CT Dose Survey
- MGH Study

Background/Motivation

Interventional CT has very different characteristics from diagnostic CT:

- Relatively lower image quality
- Many repeated short scans
- Strong metal artifact
- Procedure/Site specific
- The related CT dose/image quality has not been thoroughly studied.

Background/Motivation

- The operator determines the progress of the procedure
- High potential to utilize much higher radiation dose than diagnostic CT scans
- For a single procedure, the total effective dose could go above 100 mSv*.

*Leng S, Christner JA, Carlson SK, et al. Radiation dose levels for interventional CT procedures. AJR Am J Roentgenol 2011;197(1):W97–W103

Background/Motivation

- It is critical to understand all the related clinical procedures for CTGI.
- It will be ideal to have a quantitative parameter to measure the necessary dose range or reference level.
- Biggest challenge is the procedure complexity.

How to quantify procedure complexity


A pilot study exploring the possibility of establishing guidance levels in x-ray directed interventional procedures

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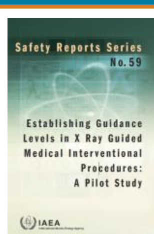
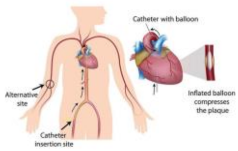


Example from Fluoroscopy

COMPLEXITY INDEX FOR PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY PROCEDURES

This substudy investigated the relationships between the complexity factors of a PTCA procedure and the observed technical factors such as FT, number of cine frames and kerma–area product (P_{KA}). Multiple linear regressions produced a CI capable of predicting the level of patient exposure. This index provides a tool for comparing individual practices and institutions as well as permitting a normalized comparison with guidance levels.

Samples of PTCA procedures were collected from cardiac centres located in Chile, Italy, Spain and Uruguay. The mean patient age at all centres ranged between 64 and 65 years (standard deviations between 8 and 12 years). The dosimetric data are summarized in Table 21. Each centre's sample was initially checked to verify data consistency and to make a subjective evaluation of the complexity mix at that centre. Relevant clinical data are summarized in Table 23.



https://www.plano.heartplace.com/services-ptca

-7-

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Complex Index for PTCA

TABLE 25. FACTORS AND WEIGHTS FOR ALL PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY CASES

All PTCA (857 cases)	Multi-vessel	Lesion type	Occlusion > 3 months	Severe tortuosity	Ostial stenting	Bifurcation stenting
Number of cases	117	161	24	25	22	58
Coefficients (min) (p value, 2 tail)	9.75 (0.000)	4.98 (0.000)	7.20 (0.002)	6.77 (0.000)		5.66 (0.000)
Weighting factors for the complexity index	1	0.51	0.73	0.69		0.58

Multivariate analysis applied to the whole sample gave the coefficients and the derived weighting factors reported in Table 25. All factors have a p (2 tail) < 0.001.

The derived weighting factors were applied to each PTCA case to derive the relative CI:

$$CI = No.ves * 1 + No.LesType * 0.51 + No.Occl3m * 0.73 + No.SevTort * 0.69 + No.BifSt * 0.58$$

Table 26 reports the mean and median values of the CI for each of the six centres. On average, more complex cases were reported from Spain B and Uruguay B than from the other centres.

Based on the derived CI, the whole sample was divided into three complexity groups:

(a) 'Simple' PTCA procedures with CI = 1;
(b) 'Medium complex' PTCA procedures with 1 < CI < 2;
(c) 'Complex' PTCA procedures with CI > 2.

Segmentation of the procedures into three complexity groups was validated using t tests. FT, total P_{KA} and fluoroscopic P_{KA} were compared between groups. All two-tail p values were < 0.001.

-8-

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CI more than patient size

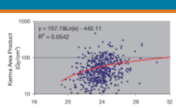

FIG. 25. Ln(P_{KA}) vs. patient equivalent diameter shows poor correlation (r^2 = 0.054) to a log trend line.

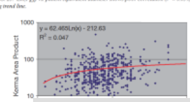

FIG. 26. Ln(KA) versus patient weight also shows poor correlation (r^2 = 0.047) to a log trend line.

TABLE 28. REFERENCE (GUIDANCE) LEVELS FOR SIMPLE, MEDIUM AND COMPLEX PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY PROCEDURES EXPRESSED IN TERMS OF FLUOROSCOPY TIME AND P_{KA}

Complexity group	Reference (guidance) levels: Fluoroscopy time (min)	Number of images	P_{KA} (%)
Simple CI = 1	15	1500	100
Medium 1 < CI <= 2	20	1650	130
Complex CI > 2	32	2250	200

Higher complexity, more imaging utilization, higher dose

-9-

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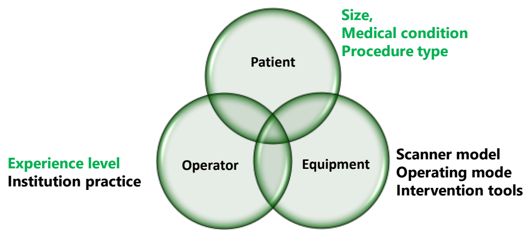
Can we do this for Interventional CT?



-10-

Key Factors

- Procedure types – Complexity/Utilization
- Operator experience
- Patient size/condition
- Institutional practice
  - Scanner models
  - Scanning modes – Helical, Axial, Mix

-11-

Utilizing available data from CT dose monitoring

- CT scan parameters as surrogates?
  - CTDIvol
  - SSDE
  - DLP
  - Total scan length
  - Number of images
  - Number of acquisitions

CTDIvol, SSDE, DLP: Dose Metric

Total scan length, Number of images, Number of acquisitions: Utilization Metric

-12-

Dose Survey Studies – Tsalafoutas, 2007

CT-Guided Interventional Procedures without CT Fluoroscopy Assistance: Patient Effective Dose and Absorbed Dose Considerations

Ioannis A. Tsalafoutas[1,2]
Virginia Tsapaki[1]
Charicleia Triantopoulou[1]
Akrivi Gorantonaki[1]
John Papailiou[1]

OBJECTIVE. The purpose of this study was to determine patient effective dose (*E*) and peak absorbed dose to the skin of the patient from various CT-guided interventional procedures performed without CT fluoroscopy assistance.

MATERIALS AND METHODS. In total, 49 interventions were retrospectively studied: 14 biopsies, 14 radiofrequency ablations, 14 abscess drainages, and seven nephrostomies. CT images were acquired from the department's PACS system and reviewed to record the scan parameters of each slice. Entrance surface dose and *E* were estimated using the Impactscan database and the related Monte Carlo conversion coefficients.

Dose Survey Studies – Tsalafoutas, 2007

TABLE 1: Results of 49 CT-Guided Interventional Procedures Performed in Adult Patients

Procedure	Patient Diameter[a] AP (cm)	Patient Diameter[a] Lateral (cm)	No. of Slices	Maximum Overlap	Peak Absorbed Dose (mGy)	DLP (mGy cm)	Effective Dose (E) (mSv)	Time (h)
Biopsies	(14 patients: 7 male, 7 female)							
Range	17–32	26–39	40–198	7–37	133–982	454–2471	5.8–46.6	0:10–1:12
Median	22.5	33.3	130	13	281	1334	23.0	0:36
Mean ± SD	24 ± 5	33 ± 4	121 ± 49	15 ± 7	348 ± 220	1418 ± 591	25 ± 11	0:39 ± 0:14
Radiofrequency ablations	(14 patients: 10 male, 4 female)							
Range	20–34	26–35	84–269	7–30	147–699	994–3232	18.4–57.2	0:36–2:34
Median	26	33.5	172	20	557	1971	35.3	1:19
Mean ± SD	26 ± 3	32 ± 3	167 ± 53	20 ± 7	494 ± 187	1976 ± 666	35 ± 12	1:22 ± 0:32
Abscess drainages	(14 patients: 8 male, 6 female)							
Range	20–31	29–40	58–146	5–15	94–315	548–1945	10.9–31.5	0:06–1:10
Median	25.3	33.9	83	8	155	840	16.2	0:41
Mean ± SD	25 ± 3	35 ± 4	90 ± 30	9 ± 3	175 ± 66	1003 ± 471	18 ± 6	0:40 ± 0:14
Nephrostomies	(7 patients: 2 male, 5 female)							
Range	20–28	29–36	37–140	4–15	75–297	440–1690	5.1–32.7	0:21–1:12
Median	21	31.5	58	8	145	710	11.5	0:51
Mean ± SD	22 ± 3	33 ± 3	76 ± 36	9 ± 5	173 ± 86	879 ± 422	15 ± 9	0:49 ± 0:28

Note—AP = anteroposterior, DLP = dose-length product.
[a]AP and lateral diameters of patient body were measured in region of maximum scan overlapping.

TABLE 2: Percentage Contribution of Each Stage of the Inerventional Procedure to Peak Absorbed and Effective Doses

Procedure and Dose	Stage A	Stage B	Stage C	Stage D	Stage E	Stage F
Biopsies						
Absorbed	0.9	17.3	14.4	11.2	47.7	8.5
Effective	2.2	63.0	3.4	2.8	15.4	9.9
Radiofrequency ablations						
Absorbed	0.5	7.2	11.1	11.3	56.5	8.5
Effective	1.7	32.6	6.0	3.5	29.8	27.5
Drainages						
Absorbed	1.8	15.1	16.3	11.1	40.6	12.8
Effective	2.4	40.3	4.8	1.4	18.8	19
Nephrostomy						
Absorbed	2.9	13.2	9.3	16.6	48.5	8.1
Effective	4.9	51.2	7.5	3.6	24.4	15.3

Note—Data are median values of percentage contribution. Stages are A, scanogram; B, diagnostic examination; C, positioning of the metal marker or grid; D, positioning of the anesthesia needle; E, positioning of the biopsy specimen acquisition needle, the radiofrequency needle, the drainage catheter, or the nephrostomy catheter; and F, lesion examination after intervention.

Dose Survey Studies – Leng, et al 2010

Radiation Dose Levels for Interventional CT Procedures

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Jodie A. Christner
Stephanie K. Carlson
Megan Jacobsen
Thomas J. Vrieze
Thomas D. Atwell
Cynthia H. McCollough

OBJECTIVE. The purpose of this study was to determine typical radiation dose levels to patients undergoing CT-guided interventional procedures.

MATERIALS AND METHODS. A total of 571 patients undergoing CT interventional procedures were included in this retrospective data analysis study. Enrolled patients underwent one of five procedures: cryoablation, aspiration, biopsy, drain, or injection. With each procedure, two scan modes were used, either intermittent (no table increment) or helical mode. Skin dose was estimated from the volumetric CT dose index ($CTDI_{vol}$) and phantom measurements. Effective dose was calculated by multiplying dose-length product (DLP) and conversion factor (k factor) for helical mode, and using Monte Carlo organ dose coefficients for intermittent mode.

Dose Survey Studies – Leng, et al 2010

TABLE 1: Volumetric CT Dose Index ($CTDI_{vol}$) for Each Scan Mode and Procedure Type

Procedure	$CTDI_{vol}$ (mGy)	
	Intermittent Mode	Helical Mode
Cryoablation (n = 42)	183 ± 338	515 ± 217
Aspiration (n = 50)	89 ± 141	65 ± 41
Biopsy (n = 329)	102 ± 105	56 ± 36
Drain (n = 103)	95 ± 124	79 ± 45
Injection (n = 47)	273 ± 222	26 ± 23

Note—Data are mean ± SD.

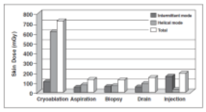

Fig. 2—Average skin dose for each type of procedure and each scan mode.

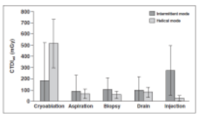

Fig. 1—Volumetric CT dose index ($CTDI_{vol}$) for each type of procedure. Error bars show range of mean ± SD.

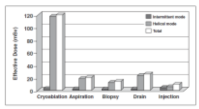

Fig. 3—Average effective dose for each type of procedure and each scan mode.

-16-

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Dose Survey Studies – Kloeckner,et al 2013

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

Radiation exposure in CT-guided interventions

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-17-

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Dose Survey Studies – Kloeckner,et al 2013

Table 1
Number of interventions, dose length products (DLPs) of peri-interventional and fluoroscopy series, and total DLPs.

Intervention type	n	DLP peri-interv. CT series (mGy cm)			DLP CTF (mGy cm)			Total DLP (mGy cm)			p
		Mean	Median	Q3	Mean	Median	Q3	Mean	Median	Q3	
Abdominal drainage	335	694	636	830	108	43	98	802	719	942	<0.001
Pleural drainage	117	490	483	566	45	23	48	535	521	630	<0.001
Liver biopsy	406	712	652	804	136	68	159	848	760	982	<0.001
Lung/pleura biopsy	242	507	481	553	91	35	97	598	538	662	<0.001
Retroperitoneal biopsy[a]	115	781	723	946	108	34	123	889	781	1098	<0.001
Mediastinal biopsy	34	549	468	649	175	89	164	724	595	891	<0.001
Renal/suprarenal biopsy	29	703	679	835	66	34	72	769	738	899	<0.001
RFA/MWA liver	85	1220	1127	1469	274	164	250	1495	1403	1906	<0.001
RFA/MWA bone	15	276	233	404	147	153	213	423	470	567	0.006
RFA/MWA lung	8	597	572	835	407	407	580	1004	932	1270	0.161
Pain block	23	787	791	896	159	109	176	946	948	1174	<0.001
Vertebroplasty	167	1313	1284	1449	179	148	216	1493	1454	1666	<0.001

[a] 111 retroperitoneal lymphatic node biopsies, 4 pancreatic biopsies.

Diagnostic scan parameters were used for peri-interventional series

-18-

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Dose Survey Studies – Yang, et al 2018

ORIGINAL RESEARCH • MEDICAL PHYSICS

Procedure-specific CT Dose and Utilization Factors for CT-guided Interventional Procedures

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From the Division of Diagnostic Imaging Physics, Department of Radiology (K.Y., M.C.D., X.L., B.L.), and Center for Image Guided Cancer Therapy, Department of Interventional Radiology (S.G.), Massachusetts General Hospital, 55 Fruit St, Boston, MA 02114; and MGH Biostatistics Center, Boston, Mass (H.Z.). Received December 18, 2017; revision requested February 26, 2018; revision received May 1; accepted May 3. **Address correspondence to** K.Y. (e-mail: *kyang11@mgh.harvard.edu*).

Conflicts of interest are listed at the end of this article.
See also the editorial by Leng in this issue.

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Dose Survey Studies – Tsapaki, et al 2019

Setting "Typical" Diagnostic Reference Levels for most common Computed Tomography guided Interventional procedures, p. 9-17
HJR
VOLUME 4 | ISSUE 1

Medical Physics ORIGINAL ARTICLE

Setting "Typical" Diagnostic Reference Levels for most common Computed Tomography guided Interventional procedures

Virginia Tsapaki, Dimitrios Fagkrezos, Sotiria Triantopoulou, Sofia Gourtsoyianni, Niki Lama, Charikleia Triantopoulou, Petros Maniatis

Medical Physics Unit and Department of Radiology, Konstantopoulio General Hospital, Nea Ionia, Greece

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Dose Survey Studies – Tsapaki, et al 2019

Table 5. Comparison of median DLP with recent international literature

	Current study		*Tsalafoutas 2007*		*Kloeckner 2013**			*Yang 2018*	
CT procedure	N	DLP	N	DLP	N	DLP	Preliminary DRLs	N	DLP
Biopsy	31	975	14	1334	826	692	982	4425	1175
Drainage	45	793	14	840	452	648	942	2365	1125
Ablation	12	1377	14	1971	85	1403	1906	679	2351
Nephrostomy	15	854	7	710					

**CT fluoroscopy technique*

Table 6. Typical DRLs in terms of DLP for biopsy, drainage, ablation and nephrostomy

	Typical DRLs
CT procedure	**DLP**
Biopsy	980
Drainage	790
Ablation	1380
Nephrostomy	850

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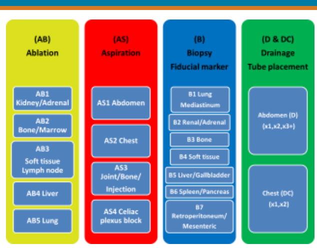
MGH Study

- To perform detailed analysis of interventional CT dose distribution at MGH.
- To explore the possibility to derive a quantitative metric to assess procedural complexity and CT utilization using CT dose metric as a surrogate.

Methods - Overview

- IRB approved retrospective study.
- Dictation reports collected for CT guided interventional cases performed at MGH from 2012 to 2017.
- CT dose data extracted using Radimetrics platform (Bayer HealthCare, Whippany, NJ).
- Four major categories and twenty-one sub-categories were created.

Methods – Intervention Category



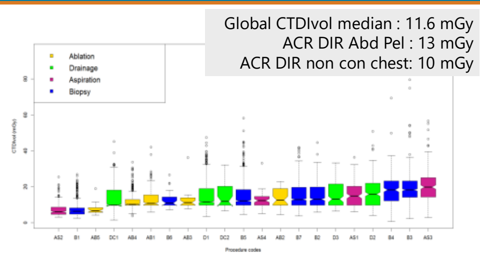
Category	Definition	No. of Procedures
Ablation		679
AB1	Renal/adrenal ablation	187
AB2	Bone ablation	43
AB3	Soft tissue ablation	28
AB4	Liver ablation	394
AB5	Lung ablation	27
Aspiration		744
AS1	Abdominal aspiration	145
AS2	Chest aspiration	282
AS3	Bone aspiration/injection	257
AS4	Celiac plexus block	60
Biopsy		4425
B1	Lung biopsy	884
B2	Renal/adrenal biopsy	547
B3	Bone biopsy	760
B4	Soft tissue biopsy	253
B5	Liver biopsy	997
B6	Pancreas biopsy	25
B7	Retroperitoneal/mesenteric biopsy	959
Drainage		2365
D1	Abdominal drainage, 1 drain	1571
D2	Abdominal drainage, 2 drains	279
D3	Abdominal drainage, 3 or more drains	127
DC1	Chest drainage, 1 drain	354
DC2	Chest drainage, 2 drains	34

Note.—There were 8213 procedures included. All procedures were CT guided.

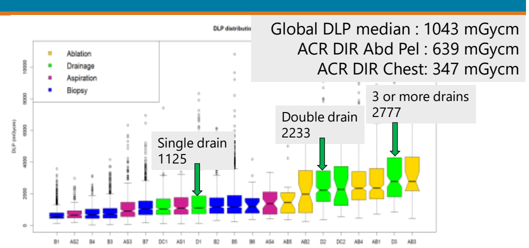
Methods – CT Dose Data

- CTDIvol (mGy): Volume CT Dose index
- DLP (mGycm): Dose-Length-Product
- SSDE (mGy)
- Scan Length (mm)
- Acquisition Count
- Number of Images

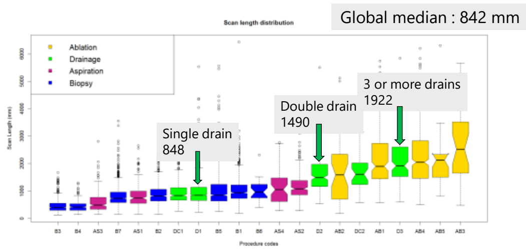
Results – CTDIvol



Results – Dose-Length-Product

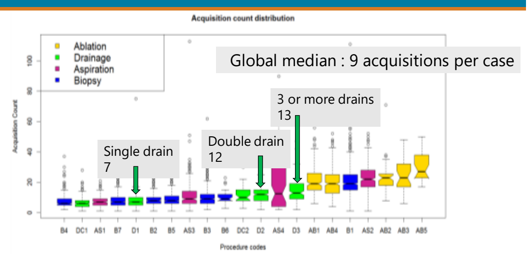


Results – Scan Length



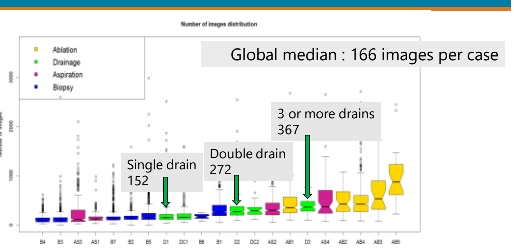
-28-

Results – Acquisition Count



-29-

Results – Number of Images



-30-

Utilization Factor

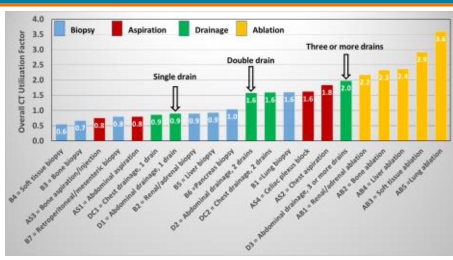
$$Utilization\ Factor\ by\ scan\ length(SL) = \frac{SL\ subcategory\ median}{SL\ global\ median},$$

$$Utilization\ Factor\ by\ acquisition\ count(AC) = \frac{AC\ subcategory\ median}{AC\ global\ median},$$

$$Utilization\ Factor\ by\ number\ of\ images(NI) = \frac{NI\ subcategory\ median}{NI\ global\ median},$$

$$Overall\ Utilization\ Factor = \frac{Utilization\ Factor\ by\ SL + Utilization\ Factor\ by\ AC + Utilization\ Factor\ by\ NI}{3}$$

Results – Complexity/Utilization Factor



Discussion

- Single institute study
- Only helical scan CT included (did not include CT fluoroscopy or ultrasound assisted procedures)
- DLP and CTDIvol slightly depends on patient size, which has a relatively small variation for this population
- Large variations between different procedures
- The complexity/utilization factors might be applicable to institutes using CT fluoroscopy

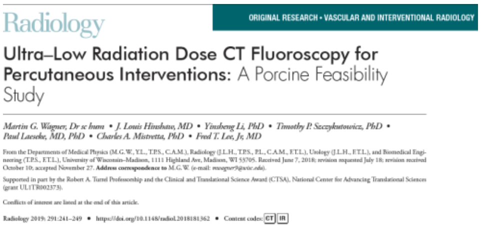
Summary

With a large number of cases analyzed and detailed categorization of CT guided interventional procedures (CTGI), consistent and procedure-specific dose metric distributions are presented and quantitative complexity/utilization factors for CTGI procedures are provided.

Future

- Robot/AI
- Different requirement for image quality
- More accurate/efficient procedure

Future



Radiology

ORIGINAL RESEARCH • VASCULAR AND INTERVENTIONAL RADIOLOGY

Ultra–Low Radiation Dose CT Fluoroscopy for Percutaneous Interventions: A Porcine Feasibility Study

Martin G. Wagner, Dr sc hum • J. Louis Hinshaw, MD • Yinsheng Li, PhD • Timothy P. Szczykutowicz, PhD • Paul Laeseke, MD, PhD • Charles A. Mistretta, PhD • Fred T. Lee, Jr, MD

From the Departments of Medical Physics (M.G.W., Y.L., T.P.S., C.A.M.), Radiology (J.L.H., T.P.S., P.L., C.A.M., F.T.L.), Urology (J.L.H., F.T.L.), and Biomedical Engineering (T.P.S., F.T.L.), University of Wisconsin–Madison, 1111 Highland Ave, Madison, WI 53705. Received June 7, 2018; revision requested July 18; revision received October 10; accepted November 27. **Address correspondence to** M.G.W. (e-mail: *mwagner9@wisc.edu*).

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Conflicts of interest are listed at the end of this article.

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-37-