



Optimizing Outcomes of Postmastectomy Breast Reconstruction With Acellular Dermal Matrix: A Review of Recent Clinical Data

Michael Zenn, MD,^a Mark Venturi, MD,^b Troy Pittman, MD,^c Scott Spear, MD,^d Geoffrey Gurtner, MD,^e Geoffrey Robb, MD,^f Alex Mesbahi, MD,^b and Joseph Dayan, MD^g

^aCARE Plastic Surgery, Cary, NC; ^bDepartment of Plastic Surgery, MedStar Georgetown University Hospital, Washington, DC; ^cPlastic and Reconstructive Surgery, Department of Plastic Surgery, MedStar Georgetown University Hospital, Washington, DC; ^dPrivate Practice Plastic Surgery, Chevy Chase, MD; ^eDepartment of Plastic Surgery, Stanford University, Palo Alto, Calif; ^fDepartment of Plastic Surgery, MD Anderson Cancer Center, Houston, Tex; and ^gDepartment of Plastic Surgery, Memorial Sloan-Kettering Cancer Center, New York, NY

Correspondence: DrZenn@CAREplasticsurgery.com

Keywords: ADM, DermACELL, AlloDerm, NSM, ICG

Published June 12, 2017

Background: This article reports on the current use of acellular dermal matrix in breast reconstruction. **Methods:** A literature review of articles on acellular dermal matrix in breast reconstruction from January 1, 2010, through December 20, 2016, was performed and analyzed for trends in acellular dermal matrix use and differences between commonly used acellular dermal matrixes. **Findings:** Clinical findings varied but include improved cosmesis and more 1-stage reconstructions using acellular dermal matrix. Superiority of sterile versus aseptic acellular dermal matrixes was noted, and the increased incidence of red breast syndrome with AlloDerm was significant. The cost-effectiveness of acellular dermal matrix use despite increased upfront costs was also highlighted. Finally, the article emphasizes the importance of well-vascularized mastectomy flaps and the use of indocyanine green angiography as an adjunct in immediate reconstruction with acellular dermal matrix.

In the last decade, advancements in surgical technique and increased use of certain surgical devices and materials have fostered a transformation in postmastectomy breast reconstruction.¹ A major innovation has been the use of acellular dermal matrix (ADM) to support prosthetic reconstructions. The main advantage of ADM use in this setting is greater control over the mastectomy space and the prosthetic device, which facilitates immediate 1- and 2-stage reconstructions.¹ Accordingly, ADMs are now used in more than 60% of

prosthetic-based reconstructions.² At the same time, nipple-sparing mastectomy (NSM) has become the standard of care and accordingly the risk for necrosis has also increased, with up to a 40% rate of skin and nipple necrosis.³

This article reviews the latest clinical data describing the use of the most commonly used and available ADM products in postmastectomy breast reconstruction. This article attempts to highlight how available ADMs may differ and which materials and techniques are supported by current evidence.

METHODS

A literature search was conducted in PubMed using the search terms “acellular dermal matrix,” “breast reconstruction,” and “mastectomy.” The initial search identified 382 items. To be included in the current article, articles were limited to human studies, published in English, from January 1, 2010, through December 20, 2016. The time period was selected to focus on more recent studies and minimize the influence of surgeon learning curve and early technical refinements. Case reports and small case series were excluded. Systematic reviews, meta-analysis, larger case series, retrospective studies, and prospective studies that evaluated the clinical use of ADM for breast reconstruction following mastectomy were included.

Included studies were evaluated for postoperative complication rates and categorized as ADM-only, ADM versus no-ADM, or ADM versus ADM. Rates of postoperative complications were also compared for aseptic and sterile ADM products.

BACKGROUND

Recent advances in mastectomy and reconstruction

As with the overall growth in mastectomies, the use of skin-sparing mastectomy and NSM has increased for breast cancer treatment and prophylaxis.⁴ Both allow for immediate reconstructions, including 1-stage (direct-to-implant or DTI) reconstructions. When insufficient skin remains to create a breast mound in 1 stage, a 2-stage approach using a tissue expander may be necessary. The 2-stage approach also allows vascularity of the mastectomy flaps to improve over time.

During prosthetic reconstructions, control and definition of the breast footplate and the implant or tissue expander are essential to optimize aesthetic outcomes. The introduction of ADM to breast reconstruction enhances surgeon control over the mastectomy space and facilitates 1- and 2-stage immediate reconstructions by strictly defining the implant pocket and off-loading the tension of the implant on the mastectomy skin envelope.

Acellular dermal matrix

The expanding class of ADM comprises biological materials derived from human or animal (bovine, porcine) tissues. The source tissues are treated using proprietary, device-specific processes to remove cells and antigens and introduce varying degrees of collagen cross-linking. The resulting acellular materials contain intact extracellular matrix (collagen fibers, elastin, hyaluronic acid, fibronectin, proteoglycans), the specific composition of which

varies across products. Available ADM are either prepared using aseptic techniques or terminally sterilized (Table 1).

Table 1. *ADM commonly used for breast reconstruction**

ADM	Source	Aseptic/sterile
AlloDerm (LifeCell Corp, Branchburg, NJ)	Human	Aseptic
AlloDerm RTU (LifeCell Corp, Branchburg, NJ)	Human	Sterile (SAL 10 ⁻³)
AlloMax (Davol Inc, Murray Hill, NJ)	Human	Sterile (SAL 10 ⁻⁶)
FlexHD (Ethicon Inc, Somerville, NJ)	Human	Aseptic
DermaMatrix (MTF/Synthes CMF, West Chester, Pa)	Human	Sterile (SAL 10 ⁻⁶)
DermACELL (LifeNet Health, Virginia Beach, Va)	Human	Sterile (SAL 10 ⁻⁶)
NeoForm (Mentor, Santa Barbara, Calif)	Human	Sterile (SAL 10 ⁻⁶)
Strattice (LifeCell Corp, Branchburg, NJ)	Porcine	Sterile (SAL 10 ⁻³)
Permacol (Covidien, Boulder, Colo)	Porcine	Sterile (SAL 10 ⁻⁶)
SurgiMend PRS (TEI Biosciences Inc, Boston, Mass)	Bovine	Sterile (SAL 10 ⁻⁶)

*ADM indicates acellular dermal matrix; RTU, ready to use; and SAL, sterility assurance level.

A core feature of ADM is its capacity to support cell ingrowth, neovascularization, and integration into host tissues. This feature contrasts with synthetic products, which incite an inflammatory process that results in degradation of the device and replacement with scar. An ideal ADM provides durable pliability and strength while minimizing inflammatory response and fostering robust tissue ingrowth and integration.

ADM and postmastectomy breast reconstruction

The use of ADM for postmastectomy breast reconstruction was first reported by Breuing and Warren⁵ in 2005. In this technique, the ADM is sutured between the lower border of the pectoralis major muscle and the chest wall, creating a sling that reestablishes the lower pole of the breast. The ADM sling augments the inferior aspect of the subpectoral pocket and provides inferolateral implant coverage and support.⁶

The use of ADM may allow for greater initial tissue expander fill volumes or facilitate single-stage (DTI) procedures, obviating the need for tissue expanders.^{6,7} With skin-sparing techniques such as NSM, the ADM sling may also improve aesthetic outcomes in the lower pole, fostering a more natural-looking breast ptosis.^{5,6}

Initial reports suggested a higher rate of certain postoperative complications associated with the use of ADM in breast reconstruction. However, the broad diversity of ADM products, patients with mastectomy, surgical techniques, and study methodologies contributes to wide variation in the outcomes of ADM studies, leaving surgeons with inconsistent guidance on postoperative risks and surgical best practices.⁸⁻¹⁰

Postoperative complications following breast reconstruction

Multiple risk factors are thought to influence the outcomes of breast reconstruction, including patient characteristics, cancer therapeutics, surgical factors, and qualities of the ADM used (Table 2).¹¹⁻²²

The baseline complication rate of 2.5% for implant reconstruction²³ has increased with ADM use. In a recent meta-analysis of 23 studies, the relative risks (RRs) for major

infection (RR = 2.74; 95% confidence interval [CI], 1.70-4.42), overall infection (RR = 1.42; 95% CI, 1.02-1.99), seroma (RR = 1.41; 95% CI, 1.12-1.78), and flap necrosis (RR = 1.44; 95% CI, 1.11-1.87) were significantly higher with ADM.²⁴ In addition, ADM was associated with reduced risks for capsular contracture and implant malposition.²⁴

Table 2. Factors associated with increased risk for complications following postmastectomy breast reconstruction*

Category	Risk factor
Patient characteristics	Age >50 y
	Smoking history
	BMI >30 kg/m ²
	Diabetes mellitus
	Larger breast size
Medical factors	Postoperative chemotherapy
	Postoperative radiotherapy
	History of radiotherapy
	Current steroid use
Surgical factors	Greater expander fill volume
	Axillary dissection
	Longer operative time
	Nipple-sparing mastectomy
	Poor-quality mastectomy flap
	Insufficient vascularity
	Thin flaps
ADM characteristics	Extensive undermining of flaps
	Aseptic vs sterile
	Perforated vs intact
	Contoured vs flat
	Greater ADM surface area

*From references 11-13, 43-51. ADM indicates acellular dermal matrix; BMI, body mass index.

RESULTS

The results of our literature review are presented in Tables 3-6. Studies are grouped by comparator groups: ADM versus no-ADM (Table 3), ADM-only (no comparator; Table 4), ADM versus ADM (Table 5), and aseptic versus sterile ADM (Table 6).

Included studies comparing the use of ADM with submuscular prosthetic coverage without ADM (Table 3) reflect inconsistent outcomes.^{15,25-35} Statistically significant differences between the ADM and non-ADM groups were reported by several studies, with higher rates of total complications, infection, and seroma in the ADM groups. One study also reported a significantly higher rate of flap necrosis with ADM.³³ Several studies reported significantly higher rates of explantation with ADM. Importantly, many studies found no significant differences in complications between groups, and some reported higher rates of explantation and unplanned return to the operating room in the non-ADM groups.

More recent studies evaluating the use of different ADMs are illustrated in Tables 4 and 5. Single-group studies (Table 4) reported outcomes with a range of ADM types.^{7,9,36-43}

There were 4 prospective and 7 retrospective studies; these included 3 multicenter and 8 single-center studies. With the exception of one study, the complication rates were relatively modest and within previously reported ranges (total complications: 3.9%-16.4%). The exception was a study from the Netherlands of Strattice (porcine ADM) use in 88 patients, which reported an extremely high complication rate (78%) and reoperation in 22.7% of cases.³⁷ This study also noted a high rate of red breast syndrome (RBS), which occurred in 14.5% of cases. The largest study (863 women, 1584 breasts), based predominantly on AlloDerm use (93% of cases), reported very low rates of seroma (1.1%) and capsular contracture (0.8%).³⁸ One study compared different material thicknesses (AlloDerm) and reported a trend toward higher complication rates with thicker ADM.³⁶

Table 3. Studies comparing reconstructions with the use of ADM to no-ADM*

Study	Method	Group	No. patients	No. breasts	Complications, %			Notes	
					All	Infection	Seroma		Necrosis
Collis et al, 2012 ²⁶	Retrospective Single center	ADM	63	106	18.9 [†]	NR	NR	TE/graft infection requiring removal similar between groups (5.75% ADM vs 4.4% control; <i>P</i> = NS); epidermolysis significantly more common with ADM (13.2% vs 1.5%; <i>P</i> < .01)	
		No-ADM	42	68	7.4 [†]				
Endress et al, 2012 ²⁷	Retrospective	SurgiMend	28	49	20.8	NR	0	5.7	Infection requiring explantation more common with no ADM (6.5% vs 1.9%; <i>P</i> = NS)
		No ADM	91	123	13		0.8	1.6	
McCarthy et al, 2012 ²⁵	Randomized Single blind Two centers	AlloDerm	36	56	17	2.8	2.8	NR	No significant differences in complications, postoperative pain, intraoperative fill volume, or pain during expansion phase (<i>P</i> > .05)
		No ADM	33	50	15	3	9.1		
Parks et al, 2012 ²⁸	Retrospective Single center	AlloDerm	232	346	NR	NR	29.9 [†]	11.9	Explantation slightly higher with ADM (11.6% vs 8.4%; <i>P</i> = NS)
		No ADM	114	165			15.7 [†]	11.5	
Peled et al, 2012 ²⁹	Prospective Nonrandomized Single center	AlloDerm	288 total	360	NR	16.9 [†]	5.3	6.1	Significantly higher rates of unplanned return to OR (<i>P</i> = .004) and explantation (<i>P</i> = .001) in the no-ADM group
		No ADM		90		27.8 [†]	4.4	11.1	
Weichman et al, 2012 ³⁰	Retrospective Single center	ADM	407 total	442	15.3 [†]	8.6 [†]	1.8	8.3	Significantly higher rate of explanation with ADM (7.7% vs 2.7%; <i>P</i> = .004)
		No ADM		186	5.4 [†]	2.7 [†]	3.2	3.2	
Liu et al, 2011 ³¹	Retrospective Single center	AlloDerm	343 total	266	19.5 [†]	6.8 [†]	7.1	13.9	
		No ADM		204	12.3 [†]	2.5 [†]	3.9	10.8	
Vardanian et al, 2011 ³²	Retrospective	ADM	123	208	29.3	1	2.4 [‡]	NR	Aesthetic outcomes improved with ADM (<i>P</i> < .05)
		No ADM	80	129	40.3	2.3	1.6		
Antony et al, 2010 ¹⁵	Retrospective	ADM	96	153	23.6	3.3	7.2	4.6	Reconstructive failure higher with ADM (2% vs 1.6%)
		No ADM	2025	2910	12.4	1.3	1.6	6.5	
Chun et al, 2010 ³³	Retrospective Single center	ADM	NR	269	NR	8.9 [†]	14.1 [†]	23.4 [†]	Significantly higher rate of reconstructive failure in the ADM group (5.9% vs 0.68%)
		No ADM		146		2.1 [†]	2.7 [†]	8.9 [†]	
Lanier et al, 2010 ³⁴	Retrospective Single center	ADM	119 total	75	46.2 [†]	28.9 [†]	15.4	5.3	Significantly higher rates of reoperation (25% vs 8%; <i>P</i> = .011) and explantation (19.2% vs 5.3%; <i>P</i> = .02) with ADM
		No ADM		52	22.7 [†]	12 [†]	6.7	15.4	
Nguyen et al, 2010 ³⁵	Retrospective Single center	AlloDerm	41	75	NR	NR	NR	NR	Significantly higher rate of explanations with ADM (8% vs 1.6%; <i>P</i> = .013); higher rate of cellulitis requiring antibiotics with AlloDerm (5.3% vs 2.8%; <i>P</i> = NS)
		No ADM	163	246					

*ADM indicates acellular dermal matrix; NR, not reported; TE, tissue expander; NS, nonsignificant; and OR, operating room.

[†]Statistically significant difference (*P* < .05).

[‡]Seroma/hematoma combined.

Table 4. Studies reporting postoperative complications with the use of ADM (no-comparator group)*

Study	Design	ADM	No. patients	No. breasts	Complications, %					Notes
					Total	Infection	Seroma	Necrosis	RBS	
Dikmans et al, 2016 ³⁷	Retrospective Multicenter	Strattice (sterile)	88	110	78	11.8	20.9	20	14.5 [†]	Reoperation in 22.7% of breasts, explantation in 11.8%
Headon et al, 2016 ³⁹	Prospective Single center	SurgiMend (sterile)	118	164	4	NR	2.5	0	NR	Explanation rate 1.2%
Rose et al, 2016 ³⁶	Retrospective 1 surgeon	AlloDerm	55 total	41 36	NR	17.1 8.3	14.6 11.1	14.6 11.1	NR	Analysis suggests a higher complication rate with thicker ADM
Salzberg et al, 2016 ³⁸	Retrospective Two centers	AlloDerm (93% of cases)	863	1584	NR	NR	1.1	NR	NR	Capsular contracture rate 0.8%
Vu et al, 2015 ⁴⁰	Prospective 1 surgeon	FlexHD (aseptic)	41	72	12.5	0	0	9.7	NR	
Vashi, 2014 ⁴¹	Case series Single center	DermaCELL (sterile)	9	15	NR	11.1	11.1	NR	0	
Rundell et al, 2014 ⁹	Retrospective Single center	AlloMax (sterile)	203	348	16.4	6.6	3.4	NR	NR	Reconstruction failure in 0.6% of breasts
Salzberg et al, 2013 ⁴³	Retrospective Single center	Strattice (sterile)	54	105	8.6	3.8	1.9	2.9	NR	Explanation rate 3.8%
Venturi et al, 2013 ⁴²	Prospective Three centers	AlloMax (sterile)	39	65	4.6	0	0	3	0	Cellulitis rate 1.5%; no explantations or seromas
Salzberg et al, 2011 ⁷	Retrospective Single center	AlloDerm (aseptic)	260	466	3.9	0.2	0	1.1	NR	No long-term complications at 36.7 mean months follow-up

*ADM indicates acellular dermal matrix; RBS, red breast syndrome; and NR, not reported.

[†]Reported as erythema/inflammation.

The question of which ADM supports the best outcomes was addressed by studies comparing 2 or more ADMs (Table 5).^{16-18,21,44-55} There were 15 retrospective studies and 1 randomized study,⁴⁸ and all study data were derived from single centers or individual surgeons. Rates of total complications ranged widely, from 8.6% to 47.7%. The one randomized trial found no significant differences between groups in total or individual complications.⁴⁸ Several studies reported significant differences between ADM in total or specific complications. However, there was no consistency in these findings between studies. Interesting significant findings included a much lower rate of RBS (0% vs 26%; $P = .0001$) and fewer days to drain removal (15.8 vs 20.6; $P = .017$) with DermaCELL compared with AlloDerm RTU (ready to use)⁴⁶; a significantly lower rate of seroma with fenestrated versus nonfenestrated ADM (11.1% vs 20%; $P = .0098$)¹⁷; and a significantly higher rate of seroma with AlloDerm versus Strattice (12.7% vs 1.4%; $P = .0003$).⁵²

Finally, studies comparing aseptic and sterile preparations of ADM are compared in Table 6.⁵⁶⁻⁶¹ All were single-center studies, all but one were retrospective, and all compared aseptic (or freeze-dried) and sterile (or RTU) AlloDerm. Overall, the studies suggest a trend toward higher rates of complications, particularly infection, with aseptic ADM. Two studies reported significantly higher complication rates with aseptic ADM than with sterile ADM (total complications: 41.9% vs 27%, $P = .046$; infection: 20% vs 8.5%, $P = .0088$).^{58,61} The outlier was a small retrospective study that reported extremely high rates of seroma with AlloDerm RTU compared with aseptic AlloDerm or no ADM (66.6% vs 8% vs 8.3%, respectively; $P = .003$).⁶⁰

Table 5. Studies comparing different ADM in postmastectomy breast reconstruction*

Study	Design	Group	No. patients	No. breasts	Complications, %					Comments
					Total	Infection	Seroma	Necrosis	RBS	
Hunsicker et al, 2017 ⁴⁴	Retrospective 2 practices	AlloDerm Strattice FlexHD Pliable	863 total	1473	8.6 (all cases)	3 (all cases)	1.1 (all cases)	5.9 (all cases)	NR	
Keifer et al, 2016 ⁴⁵	Retrospective 3 surgeons	AlloDerm RTU Cortiva	98 68	174 124	9.2 14.5	3.7 3.4	5.4 [†] 5.2 [†]	0.6 [‡] 4.8 [‡]	NR	
Pittman et al, 2016 ⁴⁶	Retrospective 1 surgeon	DermACELL AlloDerm RTU	30 28	50 50	NR	0 6	10 24	8 4	0 [‡] 26 [‡]	Shorter time to drain removal with DermACELL (15.8 vs 20.6 days; <i>P</i> = .017)
Ricci et al, 2016 ⁴⁸	Retrospective Single center	AlloDerm SurgiMend	400 240	578 374	NR	3.8 3.2	2.5 1.8	6.6 [‡] 2.9 [‡]	NR	
Zenn and Salzberg, 2016 ¹⁶	Retrospective 2 surgeons	DermACELL AlloDerm RTU	70 70	119 130	NR	1.7 0.8	0 0	1.6 (all cases)	NR	No significant differences between groups; low complication rates with expert handling
Eichler et al, 2015 ⁴⁷	Retrospective 1 surgeon	SurgiMend Epiflex	100 total	64 63	11.1 [‡] 40.6 [‡]	0 [‡] 9.4 [‡]	1.6 4.7	NR	4.8 14.1	
Mendenhall et al, 2015 ⁴⁸	Randomized Single center	AlloDerm DermaMatrix	64 64	101 98	33.6 38.8	13.9 16.3	6.1 3.1	17.8 21.4	NR	No significant differences in complications between groups
Palaia et al, 2015 ¹⁷	Retrospective Single center	AlloDerm FlexHD Fenestrated [§] Nonfenestrated [§]	134 316 362 88	179 424 488 115	NR	11.2 9.2 9.4 11.3	14 12.3 11.1 [‡] 20 [‡]	NR	NR	FlexHD had lower rate of extrusion and higher cosmetic score (<i>P</i> < .05)
Ranganathan et al, 2015 ⁴⁹	Retrospective Single center	AlloDerm FlexHD	123 186	206 315	NR	11.4 [‡] 22.6 [‡]	6.5 3.8	NR	NR	Unplanned return to OR most common complication (20.4%, no difference between groups)
Selber et al, 2015 ²¹	Retrospective Single center	AlloDerm SurgiMend	404 total	427 137	44.6 47.7	12.1 13.5	11.8 11.4	26.9 21.2	NR	
Liu et al, 2014 ⁵⁴	Retrospective Single center	AlloDerm FlexHD	382 total	175 113	NR	8.5 14.4	3 3.1	21.2 18.6	NR	No significant differences in complications between groups
Butterfield, 2013 ⁵¹	Retrospective 1 surgeon	AlloDerm SurgiMend	59 222	89 351	24.7 22.5	6.7 4.8	15.7 [‡] 8.6 [‡]	3.4 [‡] 11.1 [‡]	NR	
Hanna et al, 2013 ⁵³	Retrospective Single center	DermACELL AlloDERM	28 37	42 51	NR	NR	2.4 NR	NR	NR	Rates of infection and seroma lower with DermACELL (<i>P</i> > .05)
Seth et al, 2013 ⁵⁵	Retrospective 2 surgeons	AlloDerm FlexHD	96 159	136 233	19.1 19.3	10.3 5.2	2.2 2.1	8.1 9	NR	
Brooke et al, 2012 ⁵⁰	Retrospective Single center	AlloDerm DermaMatrix FlexHD No ADM	29 64 38 42	49 110 62 64	22 15 16 11	10 10 10 2	NR	NR	NR	
Glasberg and Light, 2012 ⁵²	Retrospective 1 surgeon	AlloDerm Strattice	96 90	126 144	21.4 [‡] 6.3 [‡]	2.4 2.1	12.7 [‡] 1.4 [‡]	0 1.4	NR	

*ADM indicates acellular dermal matrix; RBS, red breast syndrome; NR, not reported; RTU, ready to use; OR, operating room.

[†]Seroma/hematoma combined.

[‡]Statistically different between groups (*P* < .05).

[§]AlloDerm and FlexHD combined.

DISCUSSION

The introduction of ADM has revolutionized postmastectomy breast reconstruction by enabling 1- and 2-stage reconstructions, improving surgeon control over the implant and mastectomy space, and fostering improved aesthetic outcomes. Considered together, the studies included in this review demonstrate differing levels of success with all of the available ADMs. Current data do not yet identify any one optimal ADM. However, the

evidence does suggest certain trends: ADM appears to be associated with an increased risk for infection and seroma and a decreased risk for capsular contracture.

Table 6. Outcomes of studies comparing the use of aseptic ADM to sterile ADM*

Study	Design	ADM	No. patients	No. breasts	Complications, %					Notes
					Total	Infection	Seroma	Necrosis	RBS	
Klein et al, 2016 ⁵⁶	Retrospective	AlloDerm	63 total	53	NR	17	5.6	NR	NR	
	Single center	AlloDerm RTU		13		15.4	2.5			
		AlloMax (sterile)		15		0	0			
Frey et al, 2015 ⁵⁷	Retrospective	AlloDerm	620 total	91	NR	18.7	4.4	13.2 [†]	NR	Significantly lower rate of infection and minor necrosis with AlloDerm C/F vs aseptic AlloDerm, and a higher rate of minor necrosis with AlloDerm C/F vs AlloDerm RTU
	Single center	AlloDerm RTU		164		7.3	1.2	8.5 [†]		
		AlloDerm C/F		119		1.7	2.5	17.6 [†]		
		No ADM		645		3.7	1.1	5.9 [†]		
Lewis et al, 2015 ⁵⁸	Retrospective	AlloDerm	105 total	93	41.9 [‡]	11.8	8.6	NR	7.5	
	Single center	AlloDerm RTU		74	27 [‡]	10.8	2.7		2.7	
Yuen et al, 2014 ⁵⁹	Retrospective	AlloDerm	51	96	NR	NR	18.8	NR	NR	Higher rate of cellulitis with AlloDerm RTU (21% vs 12.5%; <i>P</i> = NS)
	1 surgeon	AlloDerm RTU	52	100			22			
Buseman et al, 2013 ⁶⁰	Retrospective	AlloDerm	25	NR	NR	16	8 [†]	NR	NR	
	Single center	AlloDerm RTU	9			11.1	66.6 [†]			
		No ADM	24			8.3	8.3 [‡]			
Weichman et al, 2013 ⁶¹	Prospective	AlloDerm	58	90	NR	20 [†]	4.4	13.3	NR	Rate of explantation higher with aseptic vs AlloDerm RTU (6.6% vs 1.9%; <i>P</i> = .147)
	Single center	AlloDerm RTU	64	105		8.5 [†]	1.0	10.4		
		No ADM	223	351						

*ADM indicates acellular dermal matrix; RBS, red breast syndrome; NR, not reported; RTU, ready-to-use (sterile); and C/F, contour-fenestrated.

[†] Combined major and minor flap necrosis rates.

[‡] Statistically significant difference (*P* < .05).

Differences in ADM characteristics

Important differences between ADM products include tissue source (human, bovine, porcine), methods of decellularization and antigen removal, use of supplemental cross-linking, and final preparation (aseptic vs sterile). These characteristics may influence how efficiently the ADM integrates into the host tissues, its surgical utility and durability, and tolerance by the host. Rapid host acceptance of the ADM, with minimal inflammation and an organized host response of cell infiltration into the ADM, will optimize outcomes. Differences between ADM may influence the rate and extent of these processes, possibly affecting the local inflammatory response and risks for infection and seroma formation.⁶²

Suboptimal decellularization may leave cell remnants that can induce an inflammatory response when implanted. Conversely, excessive damage to the extracellular matrix during processing (chemical cross-linking, radiation, etc) may also increase inflammation while reducing cellular and vascular infiltration of the material, limiting integration.⁶³⁻⁶⁶ The impact of these differences is illustrated by preclinical studies that evaluate components of host response on implantation of the ADM. For example, a study using a rat model demonstrated differing modes and degrees of cellular ingrowth in different ADM, with the highest degree of cell ingrowth with DermACELL and lowest with AlloDerm.⁶⁷

Aseptic versus sterile ADM

Another key difference between ADM products is their preparation as aseptic or sterile final products (see Table 1). Aseptic materials (such as FlexHD or the older form of AlloDerm) are prepared using aseptic handling throughout manufacture. Sterile ADMs are exposed to γ -radiation or other forms of terminal sterilization following manufacture and packaging. By definition, aseptic products have a sterility assurance level (SAL) of 10^{-3} ; stated another way, a chance of infection from the product itself is one in a thousand (eg, AlloDerm RTU, FlexHD). Sterile products, the standard for implantable medical devices such as breast implants, have an SAL of 10^{-6} . Therefore, the chance of an infection from a device that is sterile is one in a million (eg, DermACELL, AlloMax [ie, NeoForm]).

It has been proposed that sterile ADM may be associated with lower rates of infection than with aseptic ADM following breast reconstruction. Current evidence (Table 6) clearly supports a trend toward lower infection rates with sterile ADM. One prospective study by Weichman et al⁶¹ reported a significantly lower rate of infections with sterile versus aseptic ADM (8.5% vs 20%; $P = .0088$). Lewis et al⁵⁸ reported a significantly lower rate of total complications with sterile versus aseptic ADM (27% vs 41.9%; $P = .046$); no significant differences were found for individual complications. An older retrospective study of 31 reconstructions using NeoForm (a sterile ADM now called AlloMax) reported no cases of infection, seroma, erythema, or foreign body reaction.⁶⁸ A more recent study of 65 reconstructions in 39 patients using sterile ADM reported an overall complication rate of 4.6% (3 breasts), which included 1 case of cellulitis (1.5%) and 2 cases of mastectomy flap necrosis (3%).⁴² Similarly, studies comparing sterile ADM, such as AlloDerm RTU and DermACELL (see Table 5), have reported low rates of infection (0%-6%) with each ADM.^{16,46}

The majority of older studies of ADM in breast reconstruction utilized aseptic AlloDerm, which was replaced by sterile AlloDerm RTU in 2011. The majority of studies reporting the use of AlloDerm evaluated clinical use prior to 2011 and therefore reflect the use of aseptic ADM. These studies, although numerous, are less relevant for current products, as they demonstrate infection rates that are higher than would be expected with sterile ADM.

Patient selection for use of ADM

Overall, studies suggest that ADM may be less effective in certain patients, such as the morbidly obese (body mass index >40 kg/m²), those with prior mastectomy and radiation therapy, those with severe vascular compromise to the skin flaps immediately following mastectomy, and those who are active users of tobacco products.¹ Some authors suggest that ADMs are less effective in patients with delayed reconstruction, exposure to radiation, a history of smoking, poor skin flap perfusion, or morbidly obesity.^{1,13,69}

ADM and radiotherapy

The use of ADM in the context of radiotherapy remains controversial. Some studies have reported no difference in risk for complications when implanted ADM is exposed to radiation, whereas others have found higher complication rates in irradiated versus nonirradiated breasts with ADM.^{7,70,71} Moyer et al⁷² evaluated 27 patients who underwent bilateral reconstruction with ADM and subsequent unilateral radiotherapy. Capsular contracture occurred in 9 patients (33%) and was limited to the irradiated side; 75% of all other

complications also occurred in the irradiated side. The authors concluded that ADM limited the elastosis and chronic inflammation normally seen in irradiated implant-based reconstructions, which may mitigate capsular contracture, encouraging the use of ADM in these cases.

Red breast syndrome

The clinical signs of RBS overlap to some degree with cellulitis and infection (eg, erythema, swelling, warmth) but generally do not include fever or laboratory abnormalities.⁷³ The condition is thought to be a type of delayed hypersensitivity reaction.⁷⁴ Potential contributors to RBS include characteristics of the ADM and additives used in the packaging of some ADM.⁵⁸ Several studies reported a high incidence of RBS with certain ADMs and lower rates in others.^{46,58} In one study, the rate of RBS was 0% with DermACELL and 26% with AlloDerm RTU ($P = .0001$), suggesting that not all ADMs are equal and the host response to each may vary.⁴⁶

Optimizing mastectomy flap quality: The use of laser-assisted indocyanine green angiography

Many now believe that it is the vascularity of the mastectomy flaps that most dictates complications.¹³ Poor vascularity may occur in excessively thin, traumatized, or widely undermined flaps.⁷⁵ It follows that the recellularization and integration of any ADM will depend on adequate vascularity in the recipient area.

Laser-assisted indocyanine green angiography (LA-ICGA) is a vascular imaging methodology that can be used in the intraoperative or postoperative setting to visually assess blood flow within the mastectomy skin envelope. ICG angiography provides real-time assessment of tissue perfusion that has been correlated with clinical outcomes⁷⁶⁻⁸⁰ and guides surgical decision-making, such as intraoperative tissue resection and staging of reconstruction procedures.^{81,82} The SPY Elite system (Novadaq, Mississauga, Ontario, Canada), an advanced LA-ICGA device, assigns numeric values to levels of perfusion detected through ICG fluorescence. In one study, an SPY value of 7 or less accurately predicted flap necrosis, with 88% sensitivity and 83% specificity.⁸³

Clinical studies of the use of LA-ICGA in postmastectomy breast reconstruction have demonstrated a high degree of correlation between intraoperative perfusion values on LA-ICG (SPY) and postoperative skin flap outcomes.^{11,12,84} Two recent retrospective studies from the Mayo Clinic further support the utility of LA-ICGA for the identification of tissue at risk for complications. The first reviewed 467 consecutive reconstructions that spanned the introduction of LA-ICGA at the center (254 without and 213 with LA-ICGA).⁸⁵ The rates of total complications without SPY and with SPY use were 13.8% versus 6.6% ($P = .01$). Flap necrosis decreased significantly after LA-ICGA became available (6.7% vs 0.9%; $P = .02$). At the same time, the use of single-stage (DTI) reconstructions increased significantly (from 12% to 32%; $P < .001$) due to confidence with the vascular status of the mastectomy flaps. The second, larger analysis reviewed 942 reconstructions (590 without and 352 with LA-ICGA).⁸⁶ Again, total complications (17% vs 6%; $P < .001$) and skin flap necrosis (6% vs 1%; $P < .001$) decreased significantly with the use of LA-ICGA.

Importantly, the use of single-stage (DTI) procedures increased significantly (from 7% to 23%; $P < .001$) and NSMs were performed more frequently (28%-32%; $P = .21$).

Economic costs and benefits

The use of ADM both increases material costs and potentially reduces the need for subsequent procedures. One retrospective analysis of 367 patients undergoing prosthetic reconstructions found that average initial costs were higher when ADM was used (\$6868 with ADM vs \$5615 without ADM), but average total costs over 2 years were lower (\$11,862 vs \$12,319).⁸⁷ This shift was driven by significantly lower costs for postreconstructive events in the absence of ADM (\$5176 with ADM vs \$6704 without ADM; $P < .05$).

The type of reconstruction also influences costs.⁸⁸⁻⁹⁰ A study comparing Medicare reimbursements costs for tissue expander reconstructions, with or with ADM, and single-stage procedures with ADM found that costs were highest for tissue expander plus ADM (\$11,255.78), followed by tissue expander without ADM (\$10,934.18), and then single-stage with ADM (\$5432.02).⁸⁹ When the estimated costs of complications (based on published literature) were included, the costs of tissue expander reconstructions were similar (\$11,829.02 with ADM vs \$11,238.60 without ADM), but single-stage ADM reconstructions remained highly cost-effective (\$5909.83).

CONCLUSIONS

Increasing numbers of women are demanding techniques that improve aesthetic outcomes following reconstruction, such as skin- and nipple-sparing procedures, that can be accomplished safely in the immediate setting. The use of ADM has revolutionized the approach to immediate breast reconstruction by providing surgeons with greater control and flexibility in performing the procedure.⁹¹ Although current evidence suggests that the use of ADM may increase risk for certain complications (infection, seroma), appropriate patient selection and well-vascularized flaps can minimize or eliminate these risks.

Certain features of ADM have been promoted by surgeons for use in breast reconstruction, including a general preference for sterile ADM, which may be associated with a lower risk for infection; human ADM, because of the greater elasticity of human skin; and thinner sheets of ADM, which may facilitate integration into host tissues.¹³ As ADM-based reconstruction becomes the standard of care and the performance of specific ADMs is shown to be more and more similar, the overriding factor in ADM choice will be economic.

Acknowledgment

The authors thank Joshua Kilbridge, who was supported by Novadaq, for his assistance with the writing of this article.

REFERENCES

1. Nahabedian MY. Acellular dermal matrices in primary breast reconstruction: principles, concepts, and indications. *Plast Reconstr Surg*. 2012;130(5, suppl 2):44S-53S.

2. Ho G, Nguyen TJ, Shahabi A, Hwang BH, Chan LS, Wong AK. A systematic review and meta-analysis of complications associated with acellular dermal matrix-assisted breast reconstruction. *Ann Plast Surg.* 2012;68(4):346-56.
3. Cho JW, Yoon ES, You HJ, Kim HS, Lee BI, Park SH. Nipple-areola complex necrosis after nipple-sparing mastectomy with immediate autologous breast reconstruction. *Arch Plast Surg.* 2015;42(5):601-7.
4. Agarwal JP, Mendenhall SD, Anderson LA, et al. The breast reconstruction evaluation of acellular dermal matrix as a sling trial (BREASTrial): design and methods of a prospective randomized trial. *Plast Reconstr Surg.* 2015;135(1):20e-8e.
5. Breuing KH, Warren SM. Immediate bilateral breast reconstruction with implants and inferolateral AlloDerm slings. *Ann Plast Surg.* 2005;55(3):232-9.
6. Potter S, Browning D, Savovic J, Holcombe C, Blazeby JM. Systematic review and critical appraisal of the impact of acellular dermal matrix use on the outcomes of implant-based breast reconstruction. *Br J Surg.* 2015;102(9):1010-25.
7. Salzberg CA, Ashikari AY, Koch RM, Chabner-Thompson E. An 8-year experience of direct-to-implant immediate breast reconstruction using human acellular dermal matrix (AlloDerm). *Plast Reconstr Surg.* 2011;127(2):514-24.
8. Winters ZE, Colwell AS. Role of acellular dermal matrix-assisted implants in breast reconstruction. *Br J Surg.* 2014;101(5):444-5.
9. Rundell VL, Beck RT, Wang CE, et al. Complication prevalence following use of Tutoplast-derived human acellular dermal matrix in prosthetic breast reconstruction: a retrospective review of 203 patients. *J Plast Reconstr Aesthet Surg.* 2014;67(10):1345-51.
10. Kim JY, Davila AA, Persing S, et al. A meta-analysis of human acellular dermis and submuscular tissue expander breast reconstruction. *Plast Reconstr Surg.* 2012;129(1):28-41.
11. Vu MM, Kim JY. Current opinions on indications and algorithms for acellular dermal matrix use in primary prosthetic breast reconstruction. *Gland Surg.* 2015;4(3):195-203.
12. Winocour S, Martinez-Jorge J, Habermann E, Thomsen K, Lemaire V. Early surgical site infection following tissue expander breast reconstruction with or without acellular dermal matrix: national benchmarking using National Surgical Quality Improvement Program. *Arch Plast Surg.* 2015;42(2):194-200.
13. Nahabedian MY. Prosthetic breast reconstruction with acellular dermal matrices: achieving predictability and reproducibility. *Plast Reconstr Surg Glob Open.* 2016;4(5):e698.
14. Myckatyn TM, Cavallo JA, Sharma K, et al. The impact of chemotherapy and radiation therapy on the remodeling of acellular dermal matrices in staged, prosthetic breast reconstruction. *Plast Reconstr Surg.* 2015;135(1):43e-57e.
15. Antony AK, McCarthy CM, Cordeiro PG, et al. Acellular human dermis implantation in 153 immediate two-stage tissue expander breast reconstructions: determining the incidence and significant predictors of complications. *Plast Reconstr Surg.* 2010;125(6):1606-14.
16. Zenn MR, Salzberg CA. A direct comparison of AlloDerm-ready to use (RTU) and DermACELL in immediate breast implant reconstruction. *Eplasty.* 2016;16:e23.
17. Palaia DA, Arthur KS, Cahan AC, Rosenberg MH. Incidence of seromas and infections using fenestrated versus nonfenestrated acellular dermal matrix in breast reconstructions. *Plast Reconstr Surg Glob Open.* 2015;3(11):e569.
18. Ricci JA, Treiser MD, Tao R, et al. Predictors of complications and comparison of outcomes using SurgiMend fetal bovine and AlloDerm human cadaveric acellular dermal matrices in implant-based breast reconstruction. *Plast Reconstr Surg.* 2016;138(4):583e-91e.
19. Ibrahim AM, Ayeni OA, Hughes KB, Lee BT, Slavin SA, Lin SJ. Acellular dermal matrices in breast surgery: a comprehensive review. *Ann Plast Surg.* 2013;70(6):732-8.
20. Davila AA, Seth AK, Wang E, et al. Human acellular dermis versus submuscular tissue expander breast reconstruction: a multivariate analysis of short-term complications. *Arch Plast Surg.* 2013;40(1):19-27.
21. Selber JC, Wren JH, Garvey PB, et al. Critical evaluation of risk factors and early complications in 564 consecutive two-stage implant-based breast reconstructions using acellular dermal matrix at a single center. *Plast Reconstr Surg.* 2015;136(1):10-20.
22. Martin L, O'Donoghue JM, Horgan K, et al. Acellular dermal matrix (ADM) assisted breast reconstruction procedures: joint guidelines from the Association of Breast Surgery and the British Association of Plastic, Reconstructive and Aesthetic Surgeons. *Eur J Surg Oncol.* 2013;39(5):425-9.

23. Cordeiro PG, McCarthy CM. A single surgeon's 12-year experience with tissue expander/implant breast reconstruction, part I: a prospective analysis of early complications. *Plast Reconstr Surg.* 2006;118(4):825-31.
24. Lee KT, Mun GH. Updated evidence of acellular dermal matrix use for implant-based breast reconstruction: a meta-analysis. *Ann Surg Oncol.* 2016;23(2):600-10.
25. McCarthy CM, Lee CN, Halvorson EG, et al. The use of acellular dermal matrices in two-stage expander/implant reconstruction: a multicenter, blinded, randomized controlled trial. *Plast Reconstr Surg.* 2012;130(5, suppl 2):57S-66S.
26. Collis GN, TerKonda SP, Waldorf JC, Perdakis G. Acellular dermal matrix slings in tissue expander breast reconstruction: are there substantial benefits?. *Ann Plast Surg.* 2012;68(5):425-8.
27. Endress R, Choi MS, Lee GK. Use of fetal bovine acellular dermal xenograft with tissue expansion for staged breast reconstruction. *Ann Plast Surg.* 2012;68(4):338-41.
28. Parks JW, Hammond SE, Walsh WA, Adams RL, Chandler RG, Luce EA. Human acellular dermis versus no acellular dermis in tissue expansion breast reconstruction. *Plast Reconstr Surg.* 2012;130(4):739-46.
29. Peled AW, Foster RD, Garwood ER, et al. The effects of acellular dermal matrix in expander-implant breast reconstruction after total skin-sparing mastectomy: results of a prospective practice improvement study. *Plast Reconstr Surg.* 2012;129(6):901e-8e.
30. Weichman KE, Wilson SC, Weinstein AL, et al. The use of acellular dermal matrix in immediate two-stage tissue expander breast reconstruction. *Plast Reconstr Surg.* 2012;129(5):1049-58.
31. Liu AS, Kao HK, Reish RG, Hergueter CA, May JW Jr, Guo L. Postoperative complications in prosthesis-based breast reconstruction using acellular dermal matrix. *Plast Reconstr Surg.* 2011;127(5):1755-62.
32. Vardanian AJ, Clayton JL, Roostaean J, et al. Comparison of implant-based immediate breast reconstruction with and without acellular dermal matrix. *Plast Reconstr Surg.* 2011;128(5):403e-10e.
33. Chun YS, Verma K, Rosen H, et al. Implant-based breast reconstruction using acellular dermal matrix and the risk of postoperative complications. *Plast Reconstr Surg.* 2010;125(2):429-36.
34. Lanier ST, Wang ED, Chen JJ, et al. The effect of acellular dermal matrix use on complication rates in tissue expander/implant breast reconstruction. *Ann Plast Surg.* 2010;64(5):674-8.
35. Nguyen MD, Chen C, Colakoglu S, Morris DJ, Tobias AM, Lee BT. Infectious Complications leading to explantation in implant-based breast reconstruction with AlloDerm. *Eplasty.* 2010;10:e48.
36. Rose JF, Zafar SN, Ellsworth IV WA. Does acellular dermal matrix thickness affect complication rate in tissue expander based breast reconstruction?. *Plast Surg Int.* 2016;2016:2867097.
37. Dikmans RE, El Morabit F, Ottenhof MJ, et al. Single-stage breast reconstruction using Strattice: a retrospective study. *J Plast Reconstr Aesthet Surg.* 2016;69(2):227-33.
38. Salzberg CA, Ashikari AY, Berry C, Hunsicker LM. Acellular dermal matrix-assisted direct-to-implant breast reconstruction and capsular contracture: a 13-year experience. *Plast Reconstr Surg.* 2016;138(2):329-37.
39. Headon H, Kasem A, Manson A, Choy C, Carmichael AR, Mokbel K. Clinical outcome and patient satisfaction with the use of bovine-derived acellular dermal matrix (SurgiMend) in implant based immediate reconstruction following skin sparing mastectomy: a prospective observational study in a single centre. *Surg Oncol.* 2016;25(2):104-110.
40. Vu MM, De Oliveira GS Jr, Mayer KE, Blough JT, Kim JY. A prospective study assessing complication rates and patient-reported outcomes in breast reconstructions using a novel, deep dermal human acellular dermal matrix. *Plast Reconstr Surg Glob Open.* 2015;3(12):e585.
41. Vashi C. Clinical outcomes for breast cancer patients undergoing mastectomy and reconstruction with use of DermACELL, a sterile, room temperature acellular dermal matrix. *Plast Surg Int.* 2014;2014:704323.
42. Venturi ML, Mesbahi AN, Boehmler JH IV, Marrogi AJ. Evaluating sterile human acellular dermal matrix in immediate expander-based breast reconstruction: a multicenter, prospective, cohort study. *Plast Reconstr Surg.* 2013;131(1):9e-18e.
43. Salzberg CA, Dunavant C, Nocera N. Immediate breast reconstruction using porcine acellular dermal matrix (Strattice): long-term outcomes and complications. *J Plast Reconstr Aesthet Surg.* 2013;66(3):323-8.
44. Hunsicker LM, Ashikari AY, Berry C, Koch RM, Salzberg CA. Short-term complications associated with acellular dermal matrix-assisted direct-to-implant breast reconstruction. *Ann Plast Surg.* 2017;78(1):35-40.

45. Keifer OP Jr, Page EK, Hart A, Rudderman R, Carlson GW, Losken A. A complication analysis of 2 acellular dermal matrices in prosthetic-based breast reconstruction. *Plast Reconstr Surg Glob Open*. 2016;4(7):e800.
46. Pittman TA, Fan, KL, Knapp A, Frantz S, Spear SL. Comparison of different acellular dermal matrix (ADM) in breast reconstruction: the 50/50 study [published online ahead of print November 21, 2016]. *Plast Reconstr Surg*. doi:10.1097/PRS.0000000000003048.
47. Eichler C, Vogt N, Brunnert K, Sauerwald A, Puppe J, Warm M. A head-to-head comparison between SurgiMend and Epiflex in 127 breast reconstructions. *Plast Reconstr Surg Glob Open*. 2015;3(6):e439.
48. Mendenhall SD, Anderson LA, Ying J, et al. The BREASTrial: stage I. Outcomes from the time of tissue expander and acellular dermal matrix placement to definitive reconstruction. *Plast Reconstr Surg*. 2015;135(1):29e-42e.
49. Ranganathan K, Santosa KB, Lyons DA, et al. Use of acellular dermal matrix in postmastectomy breast reconstruction: are all acellular dermal matrices created equal?. *Plast Reconstr Surg*. 2015;136(4):647-53.
50. Brooke S, Mesa J, Uluer M, et al. Complications in tissue expander breast reconstruction: a comparison of AlloDerm, DermaMatrix, and FlexHD acellular inferior pole dermal slings. *Ann Plast Surg*. 2012;69(4):347-9.
51. Butterfield JL. 440 Consecutive immediate, implant-based, single-surgeon breast reconstructions in 281 patients: a comparison of early outcomes and costs between SurgiMend fetal bovine and AlloDerm human cadaveric acellular dermal matrices. *Plast Reconstr Surg*. 2013;131(5):940-51.
52. Glasberg SB, Light D. AlloDerm and Strattice in breast reconstruction: a comparison and techniques for optimizing outcomes. *Plast Reconstr Surg*. 2012;129(6):1223-33.
53. Hanna K, Yu D, LeGallo R, Colen D, Drake DB. Matrancell™ processed, sterilized acellular dermal matrix in implant-based breast reconstruction: clinical and histological outcomes. *Surg Forum Abstr*. 2013;S91.
54. Liu DZ, Mathes DW, Neligan PC, Said HK, Louie O. Comparison of outcomes using AlloDerm versus FlexHD for implant-based breast reconstruction. *Ann Plast Surg*. 2014;72(5):503-7.
55. Seth AK, Persing S, Connor CM, et al. A comparative analysis of cryopreserved versus prehydrated human acellular dermal matrices in tissue expander breast reconstruction. *Ann Plast Surg*. 2013;70(6):632-35.
56. Klein GM, Nasser AE, Phillips BT, et al. Is sterile better than aseptic? comparing the microbiology of acellular dermal matrices. *Plast Reconstr Surg Glob Open*. 2016;4(6):e761.
57. Frey JD, Alperovich M, Weichman KE, et al. Breast reconstruction using contour fenestrated AlloDerm: does improvement in design translate to improved outcomes?. *Plast Reconstr Surg Glob Open*. 2015;3(9):e505.
58. Lewis P, Jewell J, Mattison G, Gupta S, Kim H. Reducing postoperative infections and red breast syndrome in patients with acellular dermal matrix-based breast reconstruction: the relative roles of product sterility and lower body mass index. *Ann Plast Surg*. 2015;74(suppl 1):S30-2.
59. Yuen JC, Yue CJ, Erickson SW, et al. Comparison between freeze-dried and ready-to-use AlloDerm in alloplastic breast reconstruction. *Plast Reconstr Surg Glob Open*. 2014;2(3):e119.
60. Buseman J, Wong L, Kemper P, et al. Comparison of sterile versus nonsterile acellular dermal matrices for breast reconstruction. *Ann Plast Surg*. 2013;70(5):497-9.
61. Weichman KE, Wilson SC, Saadeh PB, et al. Sterile “ready-to-use” AlloDerm decreases postoperative infectious complications in patients undergoing immediate implant-based breast reconstruction with acellular dermal matrix. *Plast Reconstr Surg*. 2013;132(4):725-36.
62. Skovsted Yde S, Brunbjerg ME, Damsgaard TE. Acellular dermal matrices in breast reconstructions—a literature review. *J Plast Surg Hand Surg*. 2016;50(4):187-96.
63. Melman L, Jenkins ED, Hamilton NA, et al. Early biocompatibility of crosslinked and non-crosslinked biologic meshes in a porcine model of ventral hernia repair. *Hernia*. 2011;15(2):157-64.
64. Orenstein SB, Qiao Y, Klueh U, Kreutzer DL, Novitsky YW. Activation of human mononuclear cells by porcine biologic meshes in vitro. *Hernia*. 2010;14(4):401-7.
65. Pascual G, Sotomayor S, Perez-Lopez P, Bujan J, Bellon JM. Long term behavior of biological prostheses used as abdominal wall substitutes. *Histol Histopathol*. 2014;29(1):139-49.
66. Pascual G, Sotomayor S, Rodriguez M, Arteaga V, Bellon JM. Extraperitoneal and intraperitoneal behavior of several biological meshes currently used to repair abdominal wall defects. *J Biomed Mater Res B Appl Biomater*. 2015;103(2):365-72.
67. Capito AE, Tholpady SS, Agrawal H, Drake DB, Katz AJ. Evaluation of host tissue integration, revascularization, and cellular infiltration within various dermal substrates. *Ann Plast Surg*. 2012;68(5):495-500.

68. Losken A. Early results using sterilized acellular human dermis (NeoForm) in post-mastectomy tissue expander breast reconstruction. *Plast Reconstr Surg.* 2009;123(6):1654-8.
69. Hvilsum GB, Holmich LR, Steding-Jessen M, et al. Delayed breast implant reconstruction: is radiation therapy associated with capsular contracture or reoperations? *Ann Plast Surg.* 2012;68(3):246-52.
70. Nahabedian MY. AlloDerm performance in the setting of prosthetic breast surgery, infection, and irradiation. *Plast Reconstr Surg.* 2009;124(6):1743-53.
71. Spear SL, Parikh PM, Reisin E, Menon NG. Acellular dermis-assisted breast reconstruction. *Aesthetic Plast Surg.* 2008;32(3):418-25.
72. Moyer HR, Pinell-White X, Losken A. The effect of radiation on acellular dermal matrix and capsule formation in breast reconstruction: clinical outcomes and histologic analysis. *Plast Reconstr Surg.* 2014;133(2):214-21.
73. Cicilioni OJ Jr, Foles VB, Sieger B, Musselman K. *Mycobacterium fortuitum* infection following reconstructive breast surgery: differentiation from classically described red breast syndrome. *Plast Reconstr Surg Glob Open.* 2013;1(7):e50.
74. Ganske I, Hoyler M, Fox SE, Morris DJ, Lin SJ, Slavin SA. Delayed hypersensitivity reaction to acellular dermal matrix in breast reconstruction: the red breast syndrome? *Ann Plast Surg.* 2014;73(suppl 2):S139-43.
75. Patel KM, Hill LM, Gatti ME, Nahabedian MY. Management of massive mastectomy skin flap necrosis following autologous breast reconstruction. *Ann Plast Surg.* 2012;69(2):139-44.
76. Pestana IA, Coan B, Erdmann D, Marcus J, Levin LS, Zenn MR. Early experience with fluorescent angiography in free-tissue transfer reconstruction. *Plast Reconstr Surg.* 2009;123(4):1239-44.
77. Komorowska-Timek E, Gurtner GC. Intraoperative perfusion mapping with laser-assisted indocyanine green imaging can predict and prevent complications in immediate breast reconstruction. *Plast Reconstr Surg.* 2010;125(4):1065-73.
78. Newman MI, Samson MC, Tamburrino JF, Swartz KA, Brunworth L. An investigation of the application of laser-assisted indocyanine green fluorescent dye angiography in pedicle transverse rectus abdominis myocutaneous breast reconstruction. *Can J Plast Surg.* 2011;19(1):e1-5.
79. Newman MI, Samson MC. The application of laser-assisted indocyanine green fluorescent dye angiography in microsurgical breast reconstruction. *J Reconstr Microsurg.* 2009;25(1):21-6.
80. Phillips BT, Lanier ST, Conkling N, et al. Intraoperative perfusion techniques can accurately predict mastectomy skin flap necrosis in breast reconstruction: results of a prospective trial. *Plast Reconstr Surg.* 2012;129(5):778e-88e.
81. Giunta RE, Holzbach T, Taskov C, et al. Prediction of flap necrosis with laser induced indocyanine green fluorescence in a rat model. *Br J Plast Surg.* 2005;58(5):695-701.
82. Gurtner GC, Jones GE, Neligan PC, et al. Intraoperative laser angiography using the SPY system: review of the literature and recommendations for use. *Ann Surg Innov Res.* 2013;7(1):1.
83. Munabi NC, Olorunnipa OB, Goltsman D, Rohde CH, Ascherman JA. The ability of intra-operative perfusion mapping with laser-assisted indocyanine green angiography to predict mastectomy flap necrosis in breast reconstruction: a prospective trial. *J Plast Reconstr Aesthet Surg.* 2014;67(4):449-55.
84. Moyer HR, Losken A. Predicting mastectomy skin flap necrosis with indocyanine green angiography: the gray area defined. *Plast Reconstr Surg.* 2012;129(5):1043-8.
85. Harless CA, Jacobson SR. Tailoring through technology: a retrospective review of a single surgeon's experience with implant-based breast reconstruction before and after implementation of laser-assisted indocyanine green angiography. *Breast J.* 2016;22(3):274-81.
86. Harless CA, Visscher S, Jacobson SR. The clinical efficacy and financial impact of laser-assisted indocyanine green angiography on implant-based breast reconstruction at a large academic medical center. Paper presented at: Plastic Surgery Research Council, 60th anniversary, May 15, 2015.
87. Qureshi AA, Broderick K, Funk S, Reaven N, Tenenbaum MM, Myckatyn TM. Direct hospital cost of outcome pathways in implant-based reconstruction with acellular dermal matrices. *Plast Reconstr Surg Glob Open.* 2016;4(8):e831.
88. Jansen LA, Macadam SA. The use of AlloDerm in postmastectomy alloplastic breast reconstruction, part II: a cost analysis. *Plast Reconstr Surg.* 2011;127(6):2245-54.
89. de Blacam C, Momoh AO, Colakoglu S, Slavin SA, Tobias AM, Lee BT. Cost analysis of implant-based breast reconstruction with acellular dermal matrix. *Ann Plast Surg.* 2012;69(5):516-20.



90. Kilchenmann AJ, Lardi AM, Ho-Asjoe M, Junge K, Farhadi J. An evaluation of resource utilisation of single stage porcine acellular dermal matrix assisted breast reconstruction: a comparative study. *Breast*. 2014;23(6):876-82.
91. Ibrahim AM, Koolen PG, Ashraf AA, et al. Acellular dermal matrix in reconstructive breast surgery: survey of current practice among plastic surgeons. *Plast Reconstr Surg Glob Open*. 2015;3(4):e381.