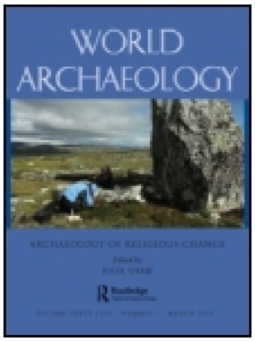

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Fluted point manufacture in eastern North America: an assessment of form and technology using traditional metrics and 3D digital morphometrics

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Abstract

Differences in Paleoindian projectile point morphology have previously been used to define technologies, infer colonization patterns, propose chronological and regional boundaries. In this study, we evaluate the effectiveness of traditional linear measurements and ratios, flake scar angles, and 3D model-based flake contours for the statistical differentiation of projectile point type(s) and reduction technique. Sixty-three fluted bifaces from eastern North America and fourteen replicate Clovis points are analyzed. Discriminant analysis shows that 3D model-based Fourier descriptors of flake scar contours are less successful than traditional metrics in correctly differentiating styles, but more successful in identifying individual knappers. Changes in the symmetry of front and back flake scars between Clovis and later fluted point styles indicate a possible shift in reduction techniques. These findings demonstrate the usefulness of both traditional and modern morphometric variables to quantify biface morphology, and address questions about social interaction and technological change in Pleistocene North America.

Keywords

Lithic technology; Paleoindians; 3D scanning; digital morphometrics; flint knapping; flake scar patterns.

Introduction

Projectile point analyses have long been a focus of artifact studies in North America. While all researchers recognize the value of understanding the use, occurrence and manufacture of other stone implements in the prehistoric record, studies of projectile point distribution, function, technology and typology far outweigh the literature on any other lithic artifact. This is especially true in Paleoindian archaeology, where the distinctive fluted points of the period have been used to: 1)

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help establish the antiquity of man in North America (e.g. Figgins 1927, 1933; Cotter 1938; see also Meltzer 1983), 2) discuss late Pleistocene subsistence strategies (Frison 1989; Kelly and Todd 1988; Meltzer 1988: 4), 3) infer population and colonization patterns (e.g. Anderson and Faught 1998; Anderson and Giliam 2000; Goebel, Waters and O'Rourke 2008; Hamilton and Buchanan 2007; Mason 1962; Morrow and Morrow 1999; Stanford 1991; Stanford and Bradley 2012), 4) propose chronological and regional boundaries (Collard et al. 2010; Bradley et al. 2008; Wright and Roosa 1966; Goodyear 1982, 2006; Haynes et al. 1992; O'Brien, Darwent, and Lyman 2001), and 5) define distinct technological techniques that may relate to cultural or regional traditions (e.g. Ahler and Geib 2000; Bradley, Collins, and Hemmings 2010; Ellis and Deller 1997; Gillespie 2007).

Given the role fluted points have played in improving our understanding of early populations in North America, techniques to refine and better characterize point technology are warranted. Across North America, fluted points are primarily defined and differentiated on the basis of physical form. Comparisons of projectile point size and shape (i.e. their morphology) have thus allowed researchers to quantify and test patterns of typological and technological variation across time and space. In early studies, typological divisions were based on subjective assessments of objects by various experts. While the trained eye of an experienced researcher remains an important analytical tool, it became clear that the analysis was made more stringent, transparent and replicable when visual assessments were supplemented with metric measurements. These measurements include simple linear distances of length, width and thickness and more intricate measurements of specialized features such as flake scar angles and basal concavity depth. Recently, advances in technology have allowed researchers to develop new ways to quantify artifact shape and variation. For example, digital photographs have been used to place and analyze landmark configurations (e.g. Buchanan and Collard 2010), and digital three-dimensional (3D) models have been used to create and decompose contour outlines (Sholts et al. 2012). While these studies have produced interesting results, the advantages, disadvantages and potential applications of these new approaches have yet to be fully explored.

In this article, we test the utility of traditional and selected modern morphometric methods for differentiating point types and tool makers in a sample of fluted projectile points. Our sample contains sixty-three fluted bifaces from eastern North America associated with five different point styles and fourteen modern replicate Clovis points associated with two different modern knappers. Specifically, we compare the performance of discriminant analysis (DA) based on conventional linear distance measurements/ratios and flake scar angles to DA based on Fourier descriptors of 3D model-based flake scar patterns for classifying 1) projectile point styles and 2) individual knapping techniques. We also compare bifacial flake scar symmetry between two temporally successive projectile point styles (i.e. Clovis and Debert-Vail) in order to investigate possible changes in manufacturing technology over time. Results demonstrate the strengths and weaknesses of these approaches for addressing particular types of questions about social interaction and technological change in North America during the late Pleistocene.

Traditional morphometric analysis of stone tools

Linear distance measurements

The most common quantitative descriptions of projectile points are linear measurements of maximum length, width and thickness, and their calculated ratios, (e.g. length/thickness; width/

thickness). However, these variables are usually not sufficient to distinguish technological or stylistic types accurately (Fig. 1a and b) (see also Morrow 1996; Shott and Trail 2010). Point re-sharpening and recycling, as well as the general variation attributed to raw material quality and package size, limit the utility of these basic measures. Thus, archaeologists have turned to the use of selected metric ratios that capture particular attributes or aspects of shape (e.g. Morrow 1996).

Indices or ratios of linear measurements describe the relationship between two variables, and can therefore in a single value provide shape information in two dimensions (2D). Moreover, ratios are an effective means to normalize and isolate shape information, by removing information related to size. Noticing varying trends in basal concavity depth among fluted point types, and recognizing the base as an important area of variation not affected by re-sharpening, Miller, Gingerich and Johanson (2010, 2013) used a ratio of basal concavity depth/basal width to compare point styles in eastern North America. As deeper-indented base styles (i.e. Redstone and Debert-Vail) are hypothesized to appear later in time than the shallower concavities of Clovis; Miller and Gingerich (2013) suggest the use of basal concavity depth/width ratio as a first approximation to delineate differences in point styles that may be separable at both a temporal and regional scale (Fig. 2).

Another effective use of ratios for comparing fluted points is to plot the basal concavity depth/width ratio against the maximum inter-flute thickness/maximum width ratio (Morrow 1996). According to Morrow (1996), these two indices relate specifically to the haft and are less affected by re-sharpening. As illustrated in her dissertation, this method successfully separates western Clovis from Debert-Vail points, as western Clovis points tend to have much shallower basal concavities and are somewhat thicker between the flutes (Morrow 1996, 194). This trend is also present in the current dataset, although the inclusion of more (possible) point types makes the clustering less discernible (Fig. 3).

Flake scar angles

In contrast to linear measurements, angles of individual flake scars on a projectile point have been described as attributes of 'execution' rather than form (Whittaker 1987). For the purpose of quantifying morphological features that reflect the technique of an individual knapper, instead of proportions that conform to a type, some researchers have analyzed and compared the orientation of left- and right-edge flake scars on both faces of individual points (Gunn 1975, 1977; Whittaker 1987). In a study of bifaces created by both modern and prehistoric knappers, there was enough variability in flake scar orientation to distinguish *some* knappers (Gunn 1975, 1977). These results also suggested that prehistoric knappers may create more tightly clustered flake scar patterns than modern knappers, probably due to the former's experience, skill level and/or specialization (Gunn 1975, 1977). The specialization aspect is important, since ancient knappers may have specialized not only in a type (of the relevant time period) but also in a specific utilitarian tool. Modern knappers, on the other hand, seldom knap to create the daily tools they need for survival. Instead they knap out of interest, and their curiosity may lead them to knap a variety of stone tools in a range of styles, arguably giving modern knappers access to a more variable repertoire of reduction strategies. Nevertheless, in testing these methods flake scar orientation patterns in tools from prehistoric Pueblo communities of the American southwest have successfully distinguished different knapping techniques, which possibly result from

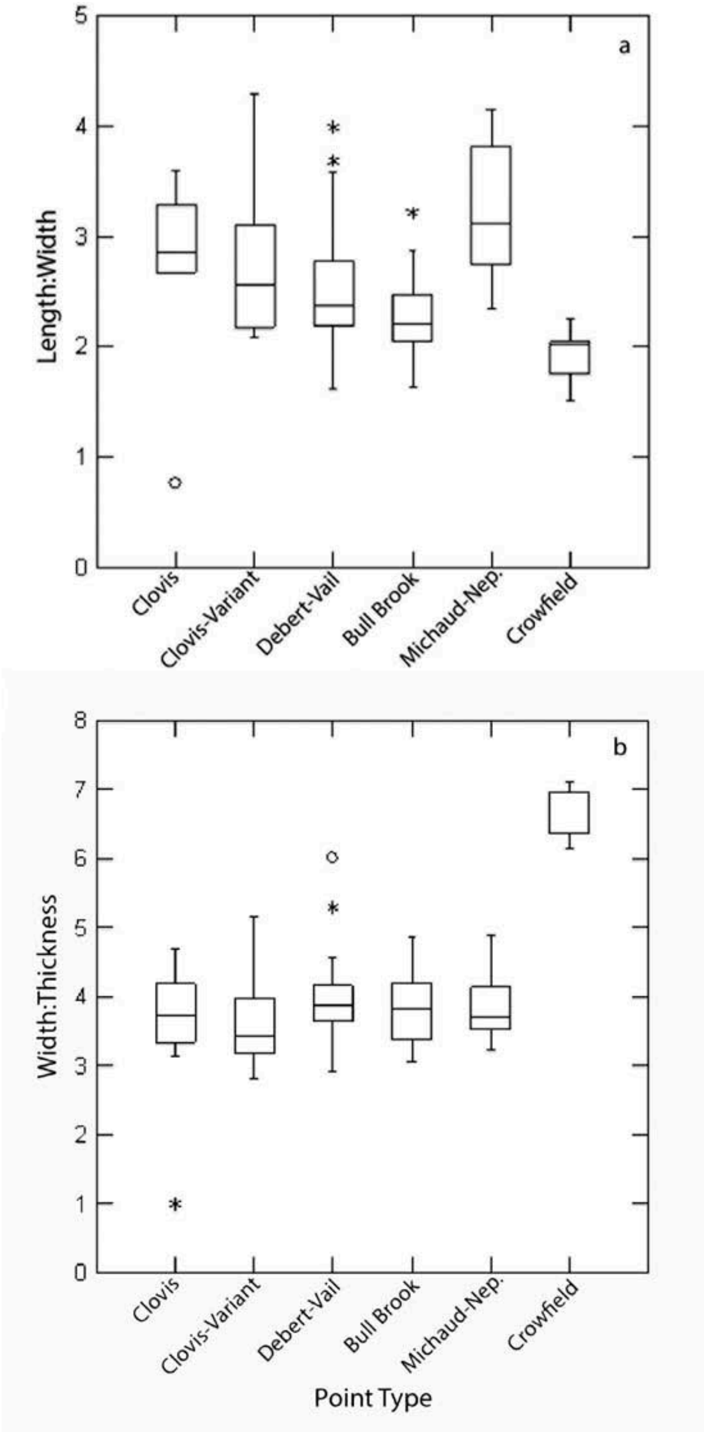

Figure 1 Distribution of variation of basic linear ratios within different northeastern point styles. Box plots show significant overlap among most styles.

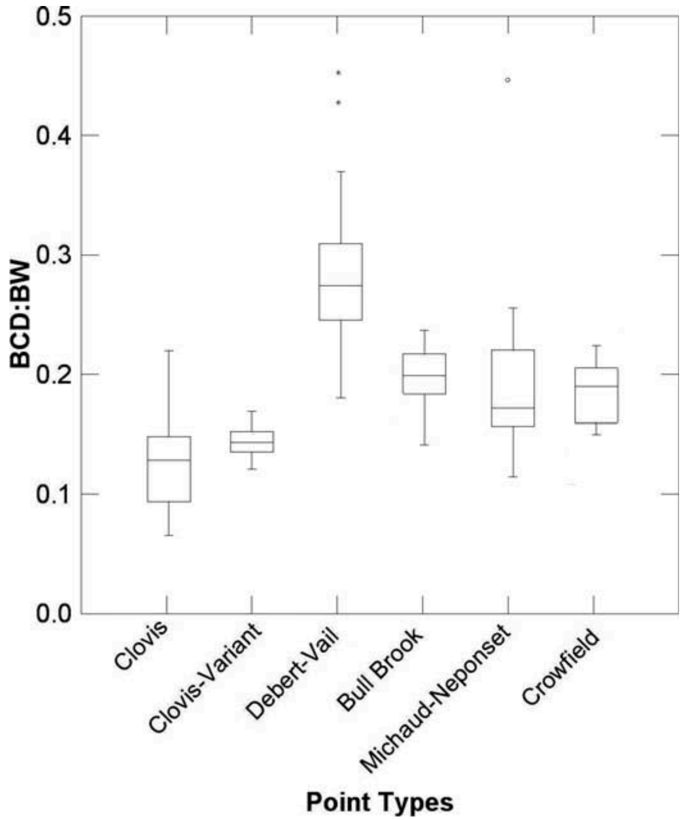

Figure 2 Distribution of variation of basal concavity depth/basal width ratio within different mortheastern types of point style. Box plots show significant differences between some styles.

differences in work habits, holding positions and flaking control (Whittaker 1987). Again, these studies may help identify aspects of morphology that are the result of an individual's style versus a particular reduction technique.

Modern morphometric analysis of stone tools

Landmark configurations

In order to capture morphological variation beyond the limitations of linear measurements, studies of Paleoindian projectile points are increasingly using statistical shape analysis of landmark configurations (e.g. Buchanan 2006; Buchanan and Collard 2007, 2010; Shott and Trail 2010; Smith 2010; Thulman 2012). Landmarks are typically defined and measured as Cartesian coordinates on 2D photographs (Thulman 2012) or digital 3D models (Shott and Trail 2010). After size standardization and alignment via procedures such as Procrustes analysis, the relative shape change at each landmark location can be quantified and visualized (Slice 2007). Landmark-based approaches have proven useful for identifying the morphological features that contribute the most to variation within or between specimens, such as Thulman's (2012) study

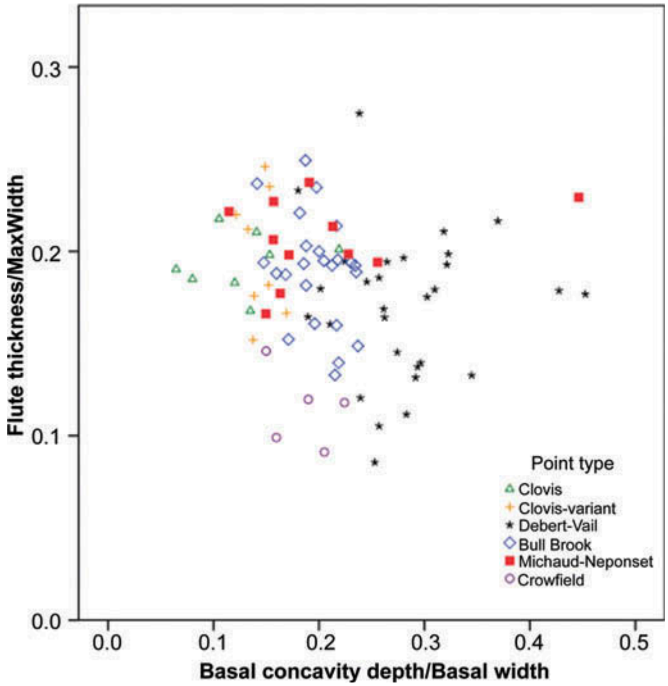

Figure 3 Scatterplot of basal concavity depth/basal width ratio versus flute thickness/maximum width ratio for eastern fluted point types, showing separation between different styles (see Morrow 1996).

demonstrating that point types from Florida are effectively differentiated by basal landmarks. In other studies, landmark configurations of overall artifact shape have shown both differences (Buchanan and Collard 2010) and similarities (Buchanan and Hamilton 2009; Smith 2010) between projectile point types defined by traditional methods.

Flake scar contours

In addition to landmarks, outlines can be used to describe relevant features as series of points from 2D or 3D images. The shape of these outlines, or contours, can be studied either with common techniques of geometric morphometrics, where the outlines are treated as landmark configurations, or via mathematical transform theory such as Fourier analysis. Using the latter approach, Sholts et al. (2012) demonstrated that outlines can be an effective means to quantify flake scar variation and bifacial symmetry in projectile points. Specifically, flake scar contours from 3D models of replicate and authentic Clovis points were used to capture patterns of flake scar depth, shape and orientation on either face of the point, and elliptic Fourier analysis was then used to decompose the outlines into series of Fourier coefficients for statistical analysis. The study showed that flake scar contours can be used to study and potentially differentiate techniques of different knappers. Results also supported the use of a uniform knapping technique among Clovis populations, which may have implications for understanding social interactions and tracking changes in technology across North America during the Paleoindian period (Sholts et al. 2012).

Materials and methods

Sample

The study sample consists of sixty-three ancient fluted projectile points from the eastern United States and fourteen modern points made by expert knappers Bruce Bradley (n = 5) and Woody Blackwell (n = 9), who were attempting to replicate Clovis points. Detailed information is provided in Table 1 and supplemental material page 2 (S2). The ancient points are mainly from well-documented archaeological sites in the north-eastern United States or are isolated finds housed by the National Museum of Natural History (Smithsonian Paleoindian collection) or the New York State Museum.

Point typology

Typological designations of the sampled points were made using the criteria presented in Bradley et al. (2008) (Table 2). This typology was used as a heuristic device to compare statistical classifications based on traditional metrics versus 3D-based contours. We do not suggest that these *a priori* groupings necessarily relate to true technological differences or appropriately reflect distinct time periods within the eastern fluted point tradition.

To be more secure in our preliminary groupings of points, large sample sets of the proposed types were selected primarily from the respective type-sites (e.g. Debert-Vail [n = 18]; Bull Brook [n = 12]). The points defined as Clovis in this study were identified by authors Gingerich and Stanford, and most displayed classic attributes such as short flutes, consistent overshot/full face flaking, low basal

Table 1 Summary of the bifaces in the sample

Point type	*Provenience*	*N*	*References*
Clovis/Clovis variant		12	
	Southeast US isolate	7	Smithsonian Collection
	Pennsylvania isolate	1	Gramly (2011)
	New York State isolate	4	NYM and Smithsonian Collection
	Shawnee-Minisink	1	Gingerich (2013)
Debert-Vail		24	
	Debert	6	MacDonald (1968)
	Vail	12	Gramly (1982, 2009)
	Northeast US isolate	1	NY State Museum
	Lamb	5	Gramly (1999)
Bull Brook		12	
	Bull Brook I	12	Robinson et al. (2009)
Michaud-Neponset/Barnes		10	
	Neponset	2	Carty and Spiess (1992)
	Intervale	1	Smithsonian Collection
	Dutchess Q. Cave	1	NY State Museum
	Ontario isolate	1	Smithsonian Collection
	Trinty, Kentucky	2	Smithsonian Collection
	New York State isolate	3	NY State Museum
Crowfield		5	
	Crowfield	1	Smithsonian Collection
	New York State isolate	3	Smithsonian Collection
	Plenge	1	Smithsonian Collection

Table 2 Description of point typology

Chronology ¹⁴C BP (Cal BP range)	*Point type*	*Abbreviated attribute list*
11,200–10,900 (13,100–12,850)	Clovis	Shallow basal concavity; flute less than ½ the length of point; no developed mid-line; fluting at or near center-line.
10,700–10,600 (12,700–12,630)	Debert-Vail	Deep basal concavity; flute ½ to ⅓ the length of point; lenticular cross-section; generally parallel sides; fluting below center-line.
10,600–10,300? (12,630–12,160)	Bull Brook	Moderate basal concavity; multiple fluting common; flute ½ to ⅓ the length of point; slightly eared on occasion; slightly divergent sides; fluting below center-line – some preforms suggest use of indirect fluting.
10,300–10,200 (12,160–11,900)	Michaud-Neponset/ Barnes	Moderate basal concavity; fully to fluted >½ the length; slight to moderate earing common; divergent sides presence of single underflute or barnes finishing flake; clearly developed mid-line.
10,100–9,900? (11,690–11,270)	Crowfield	Pentagonal in shape; medium in size; very thin and flat; narrow bases with shallow crescent-shaped concavity; multiple fluting common, which occasionally includes over flaking of flutes.

Notes: Chronology estimated from discussions in Bradley et al. (2008) and Miller and Gingerich (2013). Attribute list summarized from Bradley et al. (2008) and slightly revised for this study. Calibrated ages are presented as mean age calculated from CalPal: http://www.calpal-online.de/

concavity depths and evidence of diagonal channel flake removals from straight bases (see Bradley et al. 2010, 96–106). Some points displayed only a few of these characteristics but were found in dated deposits or with debris fitting with the Clovis tradition (e.g. sites with later-stage preforms where technology and fluting practices could be evaluated), making us confident of our designation. Points lacking such associations, but sharing three or more of the aforementioned characteristics were listed as Clovis variants. Unfortunately we did not have adequate sample sizes from the type-sites of Michaud-Neponset (or Barnes) and Crowfield to use these specimens alone. These specimens, however, are easy to type because of the distinctive fluting, the Barnes finishing flake on the Michaud-Neponset type and the general thin cross-section and distinctive blade shape of Crowfield (Fig. 4).

Linear distance measurements and flake angles

Following Morrow (1996), linear distance measurements were recorded using standard sliding calipers. From these measurements, two ratios related to base or haft morphology were calculated: basal concavity depth/basal width and maximum inter-flute thickness/maximum width. Because both distance ratios evaluate primarily aspects of the base, which is less affected by re-sharpening, points that exhibited characteristics related to retouching were included in this study; points that were re-based and showed substantial base alteration were excluded. These decisions were also influenced by the study of Buchanan and Collard (2010), who suggest that some aspects of biface shape, which relate to typological designations, are not affected by re-sharpening.

Following Gunn (1975, 1977) and Whittaker (1987), flake scar orientation angles on the right and left edges of the bifaces were measured using a clear protractor (Fig. 5, S3).

Figure 4 Examples of Michaud-Neponset (left) and Crowfield (right) points shown both as photographs and as digital 3D models. Photography credit: James Di Loreto, Smithsonian Institution.

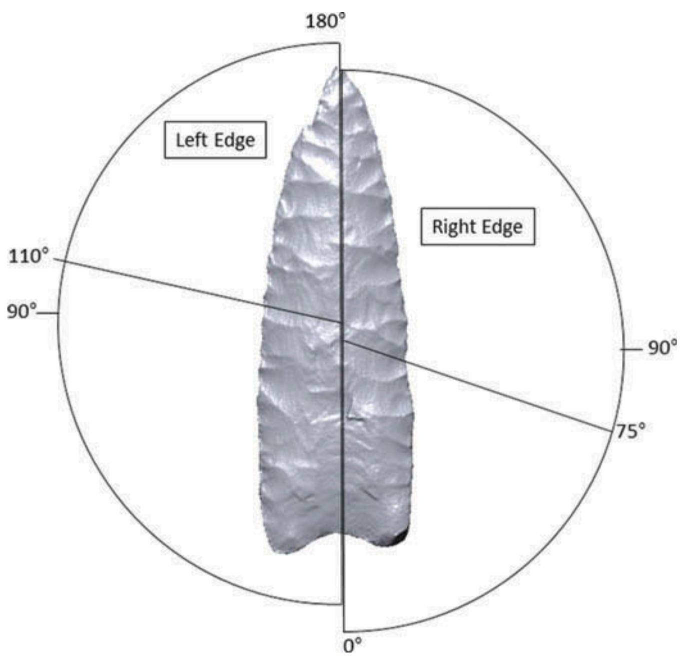

Figure 5 Illustration of the method used to record flake scar orientation. Here a protractor is used to measure the angle of each flake scar on the biface. Modified from Whittaker (1987).

3D models and flake scar contours

For all points in the sample, digital 3D surface models were created with a portable NextEngine 3D desktop laser scanner (S4, S5). Earlier studies have shown this device to produce 3D models from which landmark coordinates can be obtained and replicated with high accuracy (Sholts

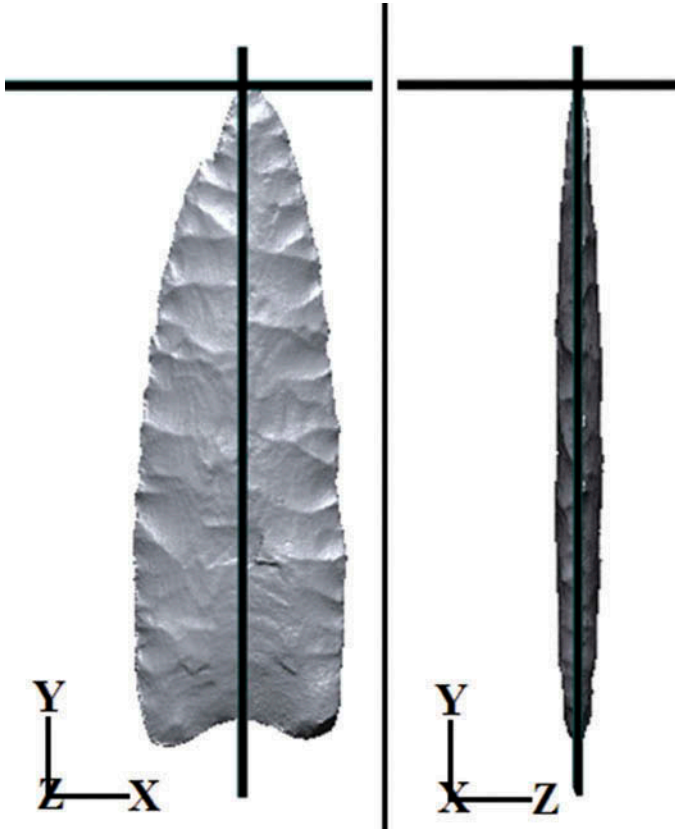

Figure 6 3D model of Clovis projectile point showing technique for defining the origin of the coordinate system down the center of the biface and perpendicular right–left (y–z) and front–back (x–y) symmetry planes.
Source: Sholts et al. (2012).
Note: Point shown is from the Drake Cache and is not included in this study.

et al. 2010, 2011). From the 3D models, flake scar contours from both faces were obtained by a previously described procedure (Fig. 6) using the Rapidworks 64 2.3.5 program (NextEngine, Inc., 2008) (Sholts et al. 2012). The contours were then converted to series of elliptical Fourier coefficients using MATLAB R2007a, version 7.4 (Mathworks Inc., 1984–2007) (Figs 7 and 8). These procedures are described in detail in earlier work by Sholts et al. (2012). As flake scar contours capture morphological variation that is not associated with the edges of bifaces, points exhibiting retouching or re-sharpening efforts were not vetted in this part of the study (see Sholts et al. 2012, 3022–3).

Statistical analysis

Discriminant analysis (DA), either as two-group discriminant function analysis (DFA) or as multi-group canonical variate analysis (CVA), was used to evaluate the *a priori* type groupings in the sample using different datasets of traditional metric and morphometric variables. Four separate analyses were performed (see Tables 3 and 4) using the Stata version 10 software. The accuracy of

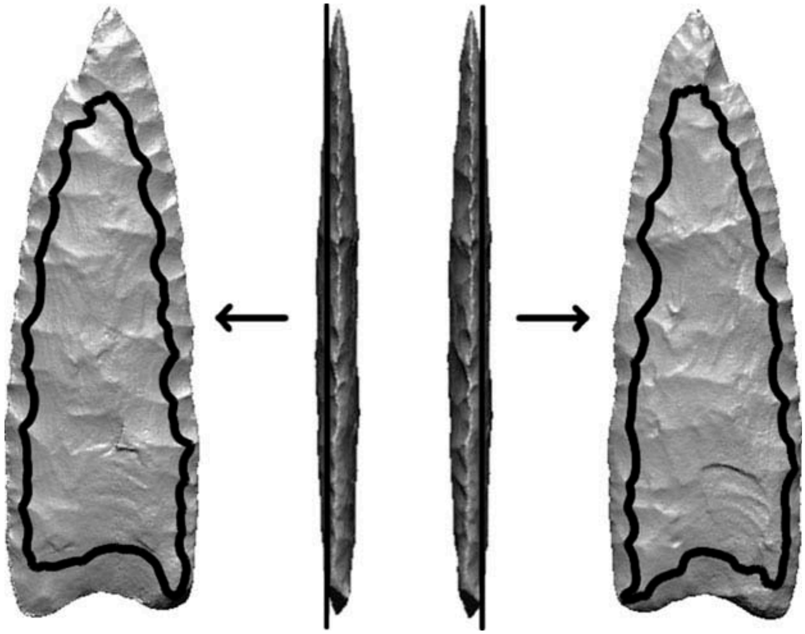

Figure 7 Following right and left biface orientation (Fig. 6), flake scar contours of the front and back sides were obtained as isoheight contours created by the intersection of the 3D model with two x−y planes, each offset a distance of ¼ total specimen thickness in the positive or negative z-direction.
Source: Sholts et al. (2012).
Note: Point shown is from the Drake Cache and not included in study.

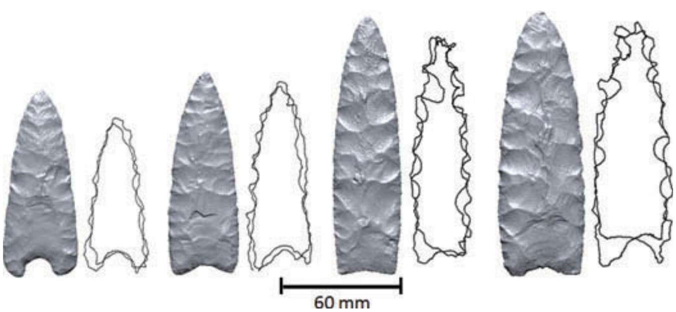

Figure 8 Example of overlaid front and back side flake scar contours allowing biface symmetry to be studied.
Source: Sholts et al. (2012).
Note: Points shown here are used as an example of the 3D modeling technique and were not included in this study.

the predictions were tested with leave-one-out cross-validation (LOOCV), where one specimen is removed from the dataset, and the remaining (n-1) specimens are used as training data. The group affinity or type category of the specimen left out is then predicted. This procedure is repeated *n* times, such that each specimen is used once as the validation sample. Although the group sizes in these analyses are small (i.e. between five and twenty-one points), due to the limited availability of

Table 3 Discriminant analysis (DA) results after leave-one-out cross-validation (LOOCV), where the rows show how points from each type group are either correctly classified (gray squares) or incorrectly classified (white squares); two separate analyses were performed, based on traditional linear distances and ratios (first number) or Fourier descriptors obtained from flake scar contours from 3D models (second number). The two right-most columns report the percentage of correct classifications for the two methods by group

Group	*Michaud-Neponset/ Barnes*	*Bull Brook*	*Clovis-variant*	*Crowfield*	*Debert-Vail*	*DA Linear distances% correct*	*DA Fourier descriptors% correct*
Michaud-Neponset/ Barnes (*n* = 9)	**6/3**	3/1	0/2	0/0	0/3	67	33
Bull Brook (*n* = 12)	1/0	**8/5**	1/3	2/1	0/3	67	41
Clovis-variant (*n* = 12)	1/1	0/3	**9/7**	1/0	1/1	75	58
Crowfield (*n* = 5)	0/0	1/0	0/0	**4/4**	0/1	80	80
Debert-Vail (*n* = 21)	0/3	3/2	1/2	1/2	**16/12**	76	57

Table 4 Discriminant function analysis (DFA) results from leave-one-out cross-validation (LOOCV), showing number of correct classifications of individual knapper for DFA functions based on either traditional flake angles or on Fourier descriptors obtained from flake scar contours from 3D models. Results of a *post hoc* analysis of additional points using the DFA based on the Fourier descriptors are also shown.

		Traditional flake angles		*3D model-based flake scar contours*	
Group	*Total N*	*%*	*N*	*%*	*N*
Blackwell	9	89	8	89	8
Bradley	5	60	3	100	5
		Post hoc test			
Blackwell	3			100	3
Bradley	5			80	4

appropriate archaeological specimens, in each discriminant analysis the number of predictor variables does not exceed the number of specimens in the smallest group.

Linear distances and ratios Using four parameters from traditional metrics (i.e. point thickness, flute thickness, average flute length and basal concavity depth/basal width), DA was performed on fifty-nine points associated with five typological groups, i.e. Bull Brook, Clovis/Clovis-variant, Crowfield, Debert-Vail and Michaud/Barnes. The four variables were selected due to their direct association with important aspects of technology of manufacture (base and flute formation) and skill (thickness). Four of the projectile points in the sample were not measureable for all four linear distances, and, since DA does not accommodate missing data, these points were excluded from the sample.

Flake scar angles The flake scar angle measurements of the fourteen Clovis points crafted by modern knappers Bradley and Blackwell provided four variables for examining knapper variation, i.e. mean scar angles for the left and right sides of both the obverse and reverse side of each biface. Discriminant analysis was conducted to classify Bradley's and Blackwell's points, and the most powerful discriminant function was found to be based on only two variables, i.e. the mean angle values for the right and left edges of the obverse face.

Fourier descriptors derived from flake scar contours The amplitude values of the Fourier coefficients for the flake scar contours from the 3D models were used in three statistical analyses.

Four Fourier descriptors (y-amplitudes 2, 13 and 20 on Face 1 and x-amplitude 7 on Face 2, selected for their discriminatory power via stepwise procedures) were employed for discriminant analysis of the same fifty-nine points used in the linear distance/ratio analysis (above).

Two Fourier descriptors (x-amplitude 16 on Face 1 and x-amplitude 30 on Face 2, selected for their discriminatory power via stepwise procedures) were used to create discriminant functions for classification of the fourteen modern projectile points used in the flake angle analysis (above).

Principal components analysis (PCA) was used to study the distribution of variation in bifacial symmetry within and between two typological groups, i.e. Clovis and Debert-Vail. Following procedures described by Sholts et al. (2012), PCA was performed on forty-four Fourier descriptors (i.e. the Fourier coefficients of harmonics 11–32) that have previously been found to define the jagged and irregular edges of the outlines (see, e.g., Fig. 8). The degree of symmetry between the front and back flake scar outlines of each projectile point (Face 1 and 2, respectively) was quantified by plotting the first principal component (PC1) score of the long-fluted face against the first principal component (PC1) score of the short-fluted face, for each specimen.

Results

Discriminant analysis classifications

For the north-eastern archaeological sample, DA based on select linear distance measurements and ratios, i.e. those hypothesized to best capture aspects of base shape and reduction (thickness and flute length), correctly predict point type for 73 per cent of the sample after LOOCV (Table 3, S3). By comparison, the four Fourier coefficients derived from the flake scar contours only classified an average of 53 per cent of the points into their designated groups after LOOCV. This is worse than the performance of the linear distances/ratios but considerably better than classification at random (which would yield a 20 per cent success rate since there are five categories). For both approaches, the best results (80 per cent correct classifications) were obtained for the Crowfield points (Table 3).

For the modern replicate sample of Clovis points, the discriminant function based on Fourier descriptors for the 3D model-based flake scar contours accurately classified more points than the function based on flake angle measurements (Table 4, S4). After cross-validation (LOOCV), the flake angle DFA accurately classified 89 per cent of the points (8/9) created by Blackwell, but only 60 per cent (3/5) of Bradley's points, yielding an average of 79 per cent (11/14) correct classifications. Also DFA based on the Fourier descriptors for the flake scar contours was able to correctly classify 89 per cent (8/9) of Blackwell's points. In addition, all of Bradley's points were correctly grouped (5/5), yielding an average success rate of 93 per cent for the Fourier descriptors. To test the potential usefulness of this particular discriminating function for differentiating points from outside the training sample, additional Clovis replicate points created

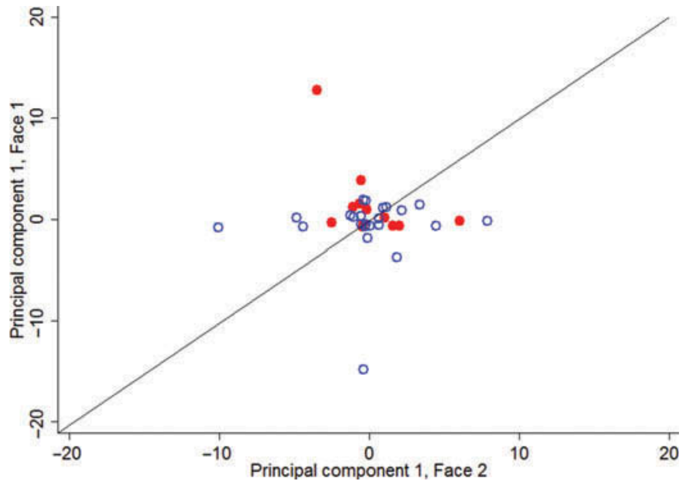

Figure 9 PCA plot of the first principal components of the front and back side of each point, plotted against each other to examine biface symmetry, for both Clovis (black circles) and Debert-Vail style points (white circles). Circles closer to the symmetry line represent more symmetric bifaces. It is clear that the Debert-Vail sample displays more variation and has more outlying specimens, and hence less overall bifacial symmetry, than the Clovis sample.

by Blackwell (n = 3) and Bradley (n = 4) were added to the flake scar contour DFA as 'unknowns', i.e. without *a priori* designation of group membership. In all but one case, these additional points were correctly predicted as belonging to either Blackwell (3/3) or Bradley (4/5), producing 88 per cent correct classifications for this *post hoc* test (Table 4).

PCA distribution

To compare bifacial symmetry in flake scar patterning in Clovis and Debert-Vail points, the first principal component (PC1) of the Fourier data for the flake scar contours of Face 1 and Face 2 for each biface was plotted against the others (Fig. 9). This procedure quantifies the matching symmetry for the two flake scar contours of each point (cf. Klingenberg, Barluenga, and Meyer 2002). For perfectly symmetric contours, the PC 1 values should be identical and thus be located on the symmetry line presented in Fig. 9. From the plot it is clear that the Clovis style points form a tighter cluster around the symmetry line, with only one clear outlier. The Debert-Vail group, on the other hand, exhibits more variation and displays multiple outliers along both axes. These results indicate higher bifacial flake scar asymmetry and more variation in the Debert-Vail group in comparison with the Clovis group.

Discussion

In this paper, we use both traditional metrics (linear distances, ratios and flake scar angles) and new digital morphometric approaches (3D model-based flake scar contours) to investigate variation in fluted point morphology and technology. Working within an existing typology

(Bradley et al. 2008) we examine how well certain attributes can classify the points into the proposed categories. As our sample we chose fluted points from eastern North America, which provide an excellent case study of technological variation and change during the Paleoindian period. Unlike in the western United States, where a relatively abrupt shift in fluted point technology occurs with the appearance of Folsom and the disappearance of Clovis around 10,900–10,800 ^{14}C BP (Haynes et al. 1992), the fluted point tradition in the east consists of a number of different 'types' or 'styles' that persist for almost 1,000 radiocarbon years (Miller and Gingerich 2013). Because the transition to the full-fluted form (i.e. the Barnes/Michaud-Neponset style) occurs much later in the East (10,200–10,300 ^{14}C BP), morphological analyses have the potential to track changes in fluted point technology across the region as groups of people moved into new parts of the continent or developed new styles and reduction techniques over time or within territories. By refining ways to quantify biface variation and manufacture we come closer to addressing these issues.

Our results show that discriminant analysis based on traditional linear distances is more effective (73 per cent correct classifications) than analysis based on flake scar contour data (53 per cent correct classifications) for classifying the points into their proposed types (Table 3). The relatively good performance of the linear distances/ratios is not surprising, as these parameters largely correlate with the criteria used to define the different types, and earlier studies (Bradley et al. 2008; Morrow 1996; Miller and Gingerich 2013; Thulman 2012) have suggested that basal variables, including thickness, can be diagnostic for different point types. However, while base design and variation in fluting may be related to manufacture technique and function, it was important to evaluate how specific patterns of biface reduction may closely follow or track changes in overall morphology.

Thus, it was not surprising that the flake scar contour data were less useful for classifying point type, as the flake scar contours were developed to capture shape information related to the reduction technique being used (Sholts et al. 2012). That flake scar contours classify point type better than a random guess is therefore somewhat unexpected, and can be interpreted in two ways: either the point types are associated with a (somewhat) characteristic reduction technique or the flake scar contours contain some shape information related to the overall morphology of the point. We favor the second explanation, especially because the second-order Fourier coefficient was found to be a powerful predictor in the discriminant analysis. As the first-order coefficients were used for size standardization, the second-order coefficients contain the lowest-order shape information, i.e. the basic shape of the point (more or less oval/narrow). The flake scar contours are expected to contain some such general shape data, and it is noteworthy that the best classification (80 per cent correct in both approaches, see Table 3) is obtained for the Crowfield points, which have a very characteristic and almost pentagonal basic shape/silhouette (Table 2). While Crowfield points also display evidence of different reduction techniques, the distinct difference in shape provides the most parsimonious interpretation to these results. For future research, it would be interesting to conduct typological point studies using 3D model-based silhouette/contours instead of flake scar contours.

Discriminant analysis was also carried out for a sample of fourteen modern replicate Clovis points made by expert knappers Bradley and Blackwell. First, a set of measured flake scar orientation angles were tested. According to previous studies by Gunn (1975) and Whittaker (1987), such data can distinguish some knappers based on the idiosyncrasies of their knapping behavior (i.e. handedness, hold and striking angles, and accuracy). Bradley and Blackwell are both highly skilled knappers, and experiments suggest that knappers with higher skill levels should produce points with more consistent flake angles, making them easier to delineate (Gunn 1975; see also Nonaka, Bril, and Rein 2010). Our DFA results show that traditional flake scar angles can easily classify the bifaces with a fairly high degree of accuracy, as 89 per cent of Blackwell's points are correctly grouped (Table 4). The data, however, do not clearly separate into broadly divided groups as 40 per cent of Bradley's points are incorrectly classified. There may be several reasons for the lower accuracy with Bradley's points; point size may have been one factor. Bradley's points are what we would call normal size points that you might find in the archaeological record (avg. length = 72.4mm), whereas Blackwell attempted to replicate a cache (avg. length = 137.5mm). Because of their small size many flake scars were overprinted and could not be reliably measured; this resulted in a smaller study sample. Bradley's points were also made over a ten- to fifteen-year period (1972–80s) and this may have led to some additional variation. Finally, a 60 per cent accuracy rate may be reasonable when using only a single attribute to analyze some populations. In using DFA to classify projectile points from Pueblo burials in the American southwest, flake scar patterning alone could correctly assign only 60 per cent of the points to their provenience (Whittaker 1987, 471).

The discriminant functions based on flake scar contour data from 3D models of the Bradley and Blackwell sample performed considerably better as 89 per cent of Blackwell's points and all of Bradley's points were classified correctly (Table 4). A *post hoc* analysis of additional points also showed extremely high accuracy, correctly assigning all three additional Blackwell and four out of five additional Bradley points. These results suggest that flake scar contours have considerable power for differentiating the techniques of individual knappers, especially given that the *post hoc* sample consists of points that were made a number of years after those in the validation sample (2001 for Blackwell and 2012 for Bradley). It should be noted that the discriminant function was based on Fourier descriptors of harmonics 16 and 30, i.e. higher-order harmonics capturing finer nuances in the outline.

In light of these results, the relatively poor performance of the flake scar contours for classifying different point types suggest that most points were manufactured with a relatively similar technique. This interpretation is consistent with the previous analysis of flake scar contours of Colby points (Sholts et al. 2012), which are atypical of Clovis due to their deeply indented bases and triangular shape, but conform to the consistency of flake scar contours represented in other Clovis points across North America (see Fig. 8). The same study also found that a high degree of bifacial flake scar symmetry appears to be a key feature of Clovis style points. Thus, the current results provide support for the hypothesis that Clovis knappers may have followed a particular reduction technique that was highly controlled or regulated in society, being passed down from master knapper to apprentice (Sholts et al. 2012, 3024).

If transmission of knowledge occurred this way, an obvious question is: when and how did it change over time? If consistent reduction strategies were a part of the early fluted point tradition and a larger social interaction sphere (Sholts et al. 2012), we might expect variation in symmetry and reduction to change with the manufacture of different point styles. To explore this possibility, we compared flake scar symmetry between Clovis points and the next dated point form in eastern North America, i.e. Debert-Vail. The appearance of a distinct or abrupt change in the symmetry of flaking patterns between Clovis and Debert-Vail points would support the idea that manufacture techniques may have changed along with morphology. In contrast, the appearance of minimal change could reflect a gradual time-transgressive shift away from particular aspects of Clovis reduction techniques. Here, reduction techniques are changing clinally, showing slow divergence over time or geographic space. These changes may, therefore, be viewed as still indicative or within the range of Clovis. In a final scenario, and if Debert-Vail is a regional type (as suggested by Bradley et al. 2008, 135), we might expect to observe greater bifacial symmetry due to the increased likelihood of seeing fewer craftsmen or a limited reduction repertoire within an archaeological sample from a specific territory (see also Gunn 1977). Furthermore, as new technologies are first introduced, there may be a period of careful copying or adoption of behaviors that result in less variation (e.g. Bettinger and Eerkens 1999; Eerkens and Lipo 2005).

The Debert-Vail points in this study clearly show more variation and bifacial flake scar asymmetry than Clovis points (Fig. 9), even though the two groups are separated by only a short period of time. Based on recent radiocarbon dates in the region (Gingerich 2011, 2013; Miller and Gingerich 2013), Clovis and Debert-Vail style points are separated by roughly 200 radiocarbon years. These two groups also exhibit differences in overall morphology, particularly with respect to their deeply indented bases, although blade shape and cross-section are somewhat similar. Given that previous (Sholts et al. 2012) and present findings suggest that point variation in bifacial flake-scar symmetry is not linked to morphology but rather to technology, these results could mark a shift or change in biface reduction techniques between Clovis and Debert-Vail styles. We hypothesize that these differences may represent a time-transgressive shift, where Clovis interaction and the direct transmission of knowledge responsible for consistent reduction techniques is breaking down, causing biface symmetry to become more variable with greater flake scar variation. Our results may support other morphometric studies (e.g. Buchanan and Collard 2007; Buchanan and Hamilton 2009), which suggest that changes in fluted point shape resulted from 'stylistic drift' and related to a colonization process or change in population dynamics. The data presented here, however, make an interesting contrast to these earlier studies, as our comparison of one later fluted point type shows a similar trend to the findings of Buchanan and Collard (2007) and Buchanan and Hamilton (2009), yet is independent of shape. Further analysis and comparisons of later fluted point types in the northeast will allow us to test this and other hypotheses to determine whether a pattern of increasing bifacial flake-scar asymmetry is seen in this region over time. With a larger and more diverse sample, other hypotheses of regionalization and copying errors can also be tested.

Conclusion

In this case study, we evaluated the effectiveness of different types of traditional and modern morphometric variables for analyzing variation in fluted point technology. While our sample sizes were small, and require that our statistical results be interpreted with caution, some trends are very clear. Our analyses indicate that traditional metrics, such as those related to base and haft morphology, better differentiates previously defined styles of fluted points in the northeastern United States than Fourier descriptors derived from flake scar contours from digital 3D models. However, these Fourier descriptors appear to be highly effective at differentiating points of the same style made by different knappers, even in comparison with traditional measurements of flake scar angles. Based on these results, we suggest that the 3D model-based flake scar contours best describe variation related to factors of point manufacture, such as technology, technique and individual knapping style. Following previous applications of these variables as a measure of bifacial symmetry (Sholts et al. 2012), points of two different styles from the northeast, Clovis and Debert-Vail, displayed patterns of variation that could be consistent with a time-transgressive shift in reduction techniques. This change in bifacial flake scar symmetry between Clovis and later Debert-Vail points may represent a change in Paleoindian social interaction. Overall, our results demonstrate how flake scar contours capture different shape information than traditional linear distance measurements of overall point morphology. Both approaches to lithic analysis appear useful in their own rights, and they should therefore be seen as complementary rather than competing methods. These findings contribute to a growing body of literature (e.g. Lycett and Chauhan 2010, and references therein) that not only shows that both 3D model-based data and traditional metrics have something to offer lithic analysts, but also highlights which techniques are more suitable for particular problems or analyses.

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