Symmetry and Middle Paleolithic Points: A Case Study of Iran's Middle Paleolithic Points

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Symmetry and Middle Paleolithic Points: A Case Study of Iran's Middle Paleolithic Points

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Abstract

The throwing capacity of Middle Paleolithic points has been an important issue since the discovery of the Neanderthal's toolbox. Homos (*Neanderthals or H. sapiens*) made thrusting points with limited or no throwing capability in the Middle Paleolithic. Projectile points as a long-range weapon replaced thrusting and guaranteed the survival of modern humans. Several attempts have been made to recognize the aerodynamic differences between Middle and Upper Paleolithic Points. However, up to now, far too little attention has been paid to the symmetry and projectile motion rules related to it. This paper measured symmetry and other morphological features, including length, width, weight, cross-sectional area, flatting, and elongation, on 280 points collected from five Iranian Middle Paleolithic sites. In addition, the Iranian Middle Paleolithic data is compared with several Middle, Upper, and Neolithic sites outside of Iran. The results indicate that the evolution of symmetry increased elongation and that proportionality in measurable characteristics was a critical factor in creating projectile points.

Keywords: Middle Paleolithic, Projectile Point, Throwing, Symmetry, fracture, Drag

1. Introduction

"Competition hypothesis" as an essential theory highlights the role of the aerodynamic ability of modern human's projectile points to overcome the Neanderthals and finally made them extinct (Shea, 2003). Shea did not have evidence to support the extensive use of stone-tipped projectiles in Africa, the Levant, or Europe until 40Ka (Shea, 2006). Churchill and Rhodes (2009) subscribe to this view by showing evidence of diversity in Scapular and ulnar morphology within and between groups of Fossil and Middle Paleolithic humans (Neandertals and early modern) attributing the origin of the projectile point to modern man from Africa and at the same time as their presence in Europe is scattered in the land of Neanderthals (Churchill and Rhodes, 2009). However, Villa and Soriano could not accept this theory based on evidence from Ethiopia and Botswana. Nevertheless, Delpiano and his colleagues (2019) believed that late Neanderthals innovated projectile points by backed artifacts hafted in different regions of Europe independently based on the large assemblage of data from unit A9 at Fumane Cave (Delpiane et al., 2019). On the other hand, Sano and his colleagues (2019) provided contradictory evidence in southern Italy. Microscopic analysis of backed lithic pieces from the Uluzzian site shows that this projectile technology was conveyed to Europe from Africa at around 45 ka by modern humans (Sano et al., 2019). As it turns out, the issue is quite challenging. However, the general opinion is that Neanderthals could not make projectile points, although subsequent experimental and archeological evidence in Abri du Maras, France, and the Northern Iberian Peninsula rejects this view (Hardy et al., 2013; Rios-Garaizar, 2016). Therefore, one should look for a way to measure the throwing capacity of the lithic points specific to these two human groups separately. Accordingly, several experimental trials have been conducted to investigate Middle Paleolithic projectile points (e.g., Shea et al. 2001; Shea et al., 2002; Sisk and Shea, 2009; Newman and Moore, 2013; Rios-Garaizar, 2016; Clarkson, 2016).

Most researchers have generally focused on measuring the cross-section area and perimeter to determine the aerodynamic features of points and throwing power, especially in the Middle Paleolithic (Hughes, 1998; Shea, 2006; Shea and Sisk, 2011; Hardy et al., 2013; Wilkins et al., 2012 & 2014, Rios-Garaizar, 2016; Clarkson, 2016, Schoville et al., 2016; Mika, 2020; Sitton et al., 2020; Mullen et al., 2021). Although there has been much debate about the validity of the morphological impact of these factors on throwing capacity (For example, Clarkson (2016)), recent experimental research seems to support their credibility (Schoville et al., 2016; Mika, 2020; Sitton et al., 2020; Mullen et al., 2021). So far, very little attention has been paid to the role of symmetry in Paleolithic projectile's functions. Accordingly, this research explores the relationship between symmetry and other morphological features in throwing capacity based on symmetry measurements using new methods, measuring morphological features of points and comparing them with points in several sites inside and outside Iran.

2. Archaeological background: The Iranian Middle Paleolithic sites

With an area of 1.648.000 square kilometers, Iran is located in southwest Asia and is surrounded by the Caspian Sea in the north and the Persian Gulf and Oman Sea in the south (Fig. 1). This area is rich in biological and geographical diversities; moreover, Iran is even more significant because of the presence of hominid remains in its neighboring regions (e.g., Shanidar in Iraqi Zagros, and Teshik-Tash in Uzbekistan in the northeast of Iranian plateau). In addition to that, significant lithic material remains, the main distinguishing cultural remains of the different Paleolithic periods, have been recorded in Iran in large numbers (Vahdati Nasab, 2010).

During the last decade, numerous Paleolithic field missions led to the discovery of a handful of Paleolithic sites across the Iranian plateau, among which are several Middle Paleolithic open sites. The points collected through systematic surface surveys of five of these sites are the subject of this research (Fig. 1): Mirak, Chah-e Jam, the Mehran plain, Kuhrang, and Bandepey. These sites are located in very different landscapes across Iran. For instance, Mirak and Chah-e Jam are situated at the northern edge of the Iranian Central Desert in very dry and arid regions (Vahdati Nasab et al., 2013; Vahdati Nasab and Hashemi, 2016). On the other hand, Bandepey is a huge lithic scatter located at the southern coast of the Caspian Sea in a Mediterranean forest (Vahdati Nasab et al., 2015). Mehran Plain and Kuhrang are both located at the Zagros Mountains; however, while Kuhrang is a high elevated site (2000 m above sea level), Mehran Plain is situated on the lowland plains of southern Zagros (Roustaei, 2010; Javanmardzadeh, 2016).

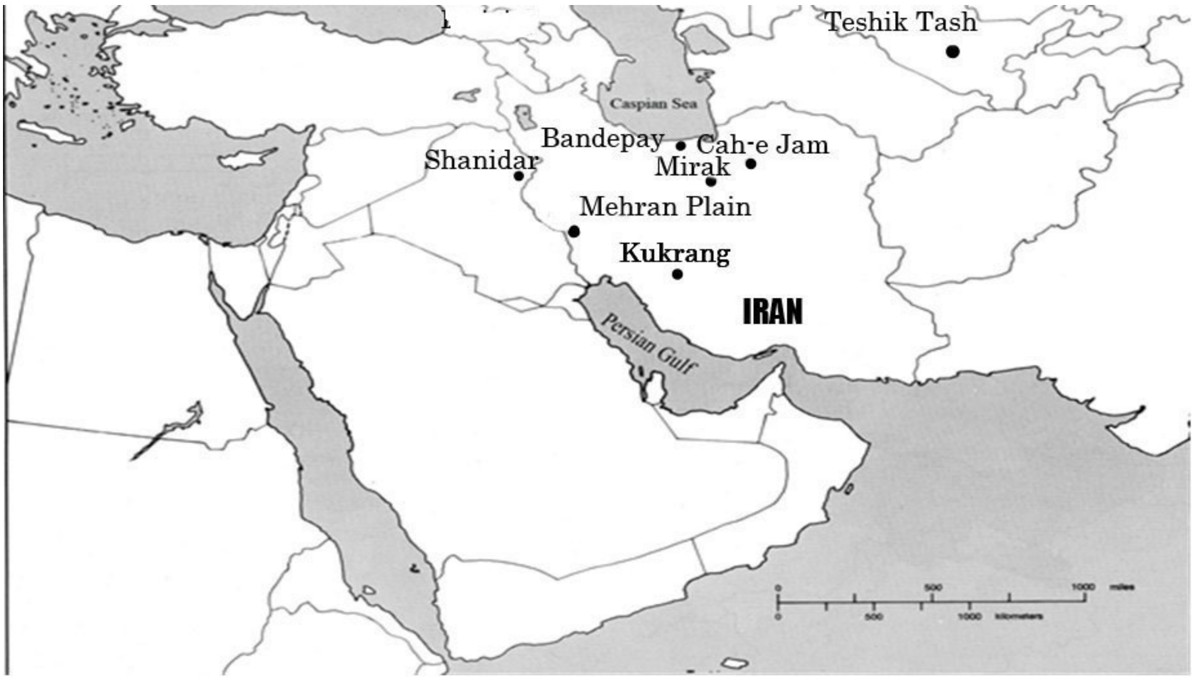


Figure 1. The location of Middle Paleolithic sites on the Iranian Plateau

The characteristics of the Middle Paleolithic period in these sites include Flake-based blank production, an abundance of prepared and châpeau de gendarme platforms, a significantly high value for the Levallois index, and the presence of tools typical of 'Mousterian' technology (Rezvani and Vahdati Nasab, 2010; Vahdati Nasab et al., 2013, Vahdati Nasab and Hashemi, 2016; Vahdati Nasab et al., 2017; Javanmardzadeh, 2016; Roustaei, 2010).

3. Methodological background: Projectile Physics Perspective

In terms of morphological features, it is clear that we are dealing with triangular points that may be functionally prehistoric weapons for hunting or conflict between population groups. However, the correct belief put forward by archaeologists is that the shape and morphological features cannot determine the performance of the artifacts (Nance, 1971; Hester and Heizer, 1973; Moss and Newcomer, 1982; Shea, 1988; O'Farrell, 1996; Plisson and Beyries 1998; Brindley and Clarkson, 2015; Chesnaux, 2014; Clarkson, 2016; Caspar and De Bie, 1996; Hauck et al., 2013). Nevertheless, first and foremost, we face two significant challenges: whether or not these lithic points were weapon armatures, and if so, what kind of weapons are the Iranian data. In this regard, there is a growing body of literature that recognizes the importance of the functional aspects of lithic points based on differences in damage patterns (Hester and Heizer, 1973; Paulsen, 1975, Odell, 1978, Moss and Newcomer, 1982; Barton and Bergman, 1982; Bergman and Newcomer, 1983; Fischer et al., 1984, Dockall, 1997; Odell, 1978; Odell and Cowan, 1986; Plisson, 2005; Roth and Plisson, 2014; Iovita et al., 2014; Kufel-Diakowska et al., 2014, Coppe and Roth, 2017, Sano et al., 2019). The main reason for this is that these researchers have experimentally shown that the performance of lithic point as tip of a spear or arrowhead may cause fracture patterns that are significant ballistic. Thus, use-wear traces can determine the specific use of a lithic point as a weapon tip (Fischer et al., 1984). Although these traces are formed in both macro-and microscopic wear traces during use, we focus only on the macro wear traces of our case study, Iranian samples, in this article. The methodological approach adopted in most studies is diagnostic methods based on diagnostic impact fractures. However, Coppe and Rots (2017) showed that these methods have drawbacks and numerous inconsistencies in their description and terminology. Therefore, they proposed an alternative method, an attribute-based approach, to describe macro-fractures (Coppe and Rots, 2017), used in this article due to its sufficient clarity. For identification, possible spear points among the Middle Paleolithic artifacts a combination of tool morphology evidence and wear/breakage analysis should be used. The means that wear and breakage patterns solitarily are not diagnostic of spear point use (Shea et al., 2002).

In 1998, Hughes examined the engineering of primitive weaponry (mass, cross-sectional area, perimeter, and the shape and durability variables from tips) from Mummy Cave. Accordingly, from a typical point of view, it is divided into four groups, including the thrusting spear, throwing spear, spear thrower, and bow (Hughes, 1998).

In projectiles, what is interesting is that the experimental research revealed a direct relationship between the use of points as spear tips and the killing power. (Wilkins et al., 2014 & 2012). Owing to the ability to penetrate the hide and create deep wounding and subsequent bleeding, the lethality of the lithic is very high (Cheshier & Kelly, 2008). In addition, there is an inverse relationship between the size of triangular stone arrow tips and the amount of penetration, with the cross-sectional area confined to less than 275 mm2 (Mika et al., 2020). However, the tips should not be too thin to break easily and be larger than the shaft to which it is attached (Sisk and Shea, 2009). For example, we can see such a relationship in the projectile point of the Uluzzian site (around45 ka) in southern Italy (Sano et al., 2019), the arrow and arrowheads of Eastern North America in the late first millennium AD (Mika et al., 2020), and the Neo-Assyrian bronze arrowhead in the site of Ziyaret Tepe, located in southeastern Turkey (Mullen et al., 2021).

However, Shea emphasizes that in the Levant, Africa, and Europe, the cross-section of the Middle Paleolithic points is large. Thus, these points are not useful for penetrating a target's body. Therefore, the lithic points were probably not widely and systematically used as projectile tips until some 40000 years ago (Shea, 2006). On the other hand, using the Australian ethnographic and experimental stone projectile tips, Clarkson showed that the cross-section area (TCSA) or perimeter (TCSP) is not a determining factor in the depth of penetration (Clarkson, 2016). Nevertheless, experimental and archeological results in the northern Iberian Peninsula's Middle Paleolithic point assemblages support the role of these factors in throwing a projectile (Rios-Garaizar, 2016). Therefore, it is essential to consider the situation from the point of view of projectile physics.

Based on the penetration equation, Prehistoric Projectile penetration is affected by four variables: mass (M), velocity (V_0), tip cross-sectional area (A), and projectile shape (C), and drag force predict the most optimal shape for penetration (Hughes, 1998).

$$\text{Penetration} = \frac{MV_0}{CA} \quad (2)$$

(Sperrazza and Kokinakis, 1968, p. 163)

The following formula (3) also determines the drag force or the friction force.

$$D = \frac{1}{2}\rho V_t^2 A.C. \quad (3)$$

These formulas show a direct relationship between the increasing coefficient of the drag and reducing speed between the drag and cross-section areas. The drag force formula shows that the smaller the cross-sectional area, the lower the drag force acting upon the projectile. Accordingly, the cross-section area can be a good factor from the drag reduction point of view. Furthermore, in the throwing motion, the shape of the trajectory and its range are affected by the drag (Ang, 2013). Accordingly, it seems that the cross-section area affected the drag amount, although its effect depends on other factors. For example, the joint between the point and the shaft is a key criterion in the performance of the spear (Pétillon et al., 2011). For more explanation, width has a vital role in drag amount, and as a result, in weapon performance. Due to a more assured linkage between tool, mastic, handle, and counteracting lateral bending forces during impact, more width at slow-speeds weapons such as hand-delivered spears can be considered an advantage. However, at high-speeds projectiles, it increases the drag (Shea et al., 2002). Decreasing weight, surface area, and cross-section will reduce the drag and steering effect that the larger points sometimes have (Klopsteg 1943:189). In addition, the length of the projectile has an effect on the amount of drags (Butler 1973:91). Accordingly, drag in the throwing motion decreases by increasing the length and reducing the cross-section. Thus, projectile shape, due to its effect on drag, is a vital variable in the amount of penetration into the target. So that in order to create tissue cleavage and open a fatal hole, the effective shape acts as a long and lanceolate tip (Huges, 1988). However, haft drag in non-thrusting spears is more important due to the lack of control of the hunter muscle (Churchill, 1993).

In addition, a growing body of literature experimentally recognizes the importance of morphological characters in terms of being ballistic and its performance in projectile efficiency (Shea et al., 2001 & Shea et al., 2002 & Shea, 2006 & Sick and Shea, 2009, 2011& Salem and Churchill, 2016). Thus from Shea and colleagues point of view (2011),“Longer and narrower points minimize drag and improve the effectiveness of high-speed projectile weapons such as spearthrower darts and arrows; but , within the context of relatively low-speed weapons, shorter and wider points withstand mechanical stresses more effectively than long and narrow points.”

For producing the skeletal trauma, thrusting and non-thrusting weapons are fundamentally different in terms of the mass, average velocity, kinetic energy, and momentum transmitted to their target (Churchill et al., 2009). For example, Levallois point as spear points act effectively and create widening wounds and fractured ribs (Shea et al., 2001) whereas complex projectile technology makes low-mass projectiles, creating a lethal puncture wound on a target proper long-range distance (Shea and Sisk, 2010). The difference in damage pattern, for example, the extensive injury around the site of impact using a hand-thrusting weapon, is due to the difference in the morphological characteristics of the tips and high kinetics and momentum (Churchill et al., 2009).

Materials and Methods

There are different ways to measure symmetry in two-dimensional space. However, 3D methods have recently demonstrated that the third dimension and the degree proportion of preparation removals are critical for increasing symmetry (Feizi et al., 2018). For example, based on previous research on the points of the mentioned site, it was proved that the deviation of symmetry in most Middle Paleolithic points has a similar pattern (Feizi et al., 2019). We think that the results are likely to be related to the interaction between the proportion of preparation removals and symmetry and the effect of these interactions on morphology (Feizi et al., 2018; Feizi et al., 2019). Thus, we calculated the deviation from the symmetry of 5 Iranian areas with the three-dimensional method. However, we used a straightforward method called the quadrangle technique to compare our data with other sites.

In summary, in our 3D method, all lithic points were scanned, and each lithic point was transformed into a points cloud by the scanner. Each points cloud was then transformed into a 3D lithic point by Geomagic software (version 2013). Thus, using the software two surfaces were created: a [1]CAD Model (reference model) and a Mesh Model (test model).

For creating a meshed surface, the software will pass a triangle from any three points, not on a straight line in points cloud. This operation leads to doing math calculations on a triangulated surface. For example, if we calculate a lithic point area, the software quickly collects the triangle areas that cover all surface points and calculates the total area of that lithic point. In addition to the countable surface, we make a Reference Model (CAD) to calculate the deviation of each point from the symmetry mode. The CAD is an incomputable surface in which all topographic characteristics are determined precisely and used only for comparison. Then the two levels are aligned so that the left side of the lithic point is set on the right side, like a veneer. With this logic, the more symmetrical the two sides of the lithic point are, the more accurately the surfaces are placed on each other. In this position, the upper surface acts as a suitable veneer. This alignment is done with a particular technique and is the most accurate. The software compares the symmetry of the lithic point concerning all the topographical features of the two sides. At the final step, the degree of deviation from symmetry is defined as a series of numbers, and then the obtained data are analyzed by SPSS 23 (Feizi et al., 2018).

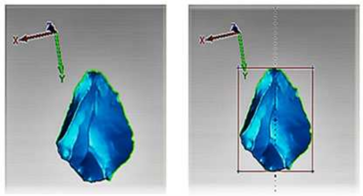


Figure 2. The quadrangle is halved, and each triangular lithic point is divided into two parts (Feizi et al., 2018).

In the paper, any lithic point or any other 2D or 3D dimensional shape is inscribed in a quadrangle so that four (or three) vertices of the lithic point are tangent to the four sides of the quadrangle. Next, MB-ruler[2] is used to cut the quadrilateral from its center. The ruler, designed by Markus Bader, is a high-flexibility ruler that measures distances and angles from a computer screen and distances from maps and aerial photographs. Thus, the quadrangle is halved without paying attention to the point shape. It means that if a lithic point is symmetrical, it will be half from its symmetrical axis with the quadrangle. Accordingly, as shown in Figure 2, the quadrangle is halved, and each triangular lithic point is divided into two smaller triangles (the right and left), and the areas of the two triangles are calculated (Fig. 2). If the left and right are equal, then the difference between the two sides of the lithic point will be equal to zero. Hence, symmetry is perfect. However, perfect symmetry is impossible in reality, and there is always a numeric value (SL− SR/= 0). This numeric value is the deviation of ideal symmetry (D.S.) (3), and I.D.S. (4) is equal to D.S divided by the total area of a lithic point (S.T.) (Feizi et al., 2018).

[1] Computer-aided design (CAD)

[2] © Markus Bader - MB-Software solutions

$$\text{D.S} = |S_L - S_R| \qquad (3)$$

$$\text{I.D.S} = \frac{|S_L - S_R|}{S_T} \qquad (4)$$

Accordingly, we compared the symmetry deviation of lithic points in the Middle and Upper Paleolithic using the quadrangle technique.

It should be noted that this article uses two-dimensional and three-dimensional techniques for two different purposes. All comparisons were performed with a two-dimensional method due to the lack of access to scanned points from other regions. However, to clarify the cognitive importance of symmetry in the third dimension of lithic point, the three-dimensional technique was used only in the five sites we access. The advantage of the two-dimensional method is the simplicity of this method so that even without the use of calculation I.D.S., only by enclosing the point in a quadratic and passing the axis through its center can the differences be intuitively compared.

In this research, 340 Iranian lithic points were scanned in the Rock Mechanics Laboratory, Tarbiat Modares University (Tehran, Iran), using Optic Scan3D Scanner and Version 2.2. Once the digitization was completed, 3D images were analyzed and compared by Geomagic software (version 2013). Also, a Marcus Bader Ruler was used to bisect each lithic point (version 5.1). Then, their symmetry was measured in two- and three-dimensional space.

We measured the symmetry deviation of lithic points in the middle Paleolithic sites of Iran, including Mirak, Chah e jam, Mehran Plain, Kouhrangh, and Bandepay by 3D method.

In total, 280 points were selected from Iranian sites for this research, all of which have been confirmed for having diagnostics signs of Middle Paleolithic industries (e.g., Levallois technique, prepared and faceted platforms, retouches). Table 1-1 summarizes the quantity of Iranian Middle Paleolithic points chosen for this research. In addition, we studied the Upper Paleolithic points in Iran, including Yafteh cave (Otte, et al., 2007), Arjaneh (Hole, 1970), Boof cave (Ghasidian, 2012), and Galeh ghosheh site (Conard, et al., 2009).

Site	Mirak	Chah-e Jam	Bandepey	Kuhrang	Mehran Plain	
Number	143	57	27	22	31	
Total						**280**

Table 1-1. The number of Iranian Middle Paleolithic points that were selected to measure symmetry.

In the next step, to determine the function of the points, we first focus on macro fractures description using Coppe and Rot's attribute-based approach. For this purpose, in addition to the 280 points that allowed us to measure symmetry, we returned 60 broken points, including only the proximal or distal parts of the points, removed from the collection to reduce errors. In total, fractures were analyzed for 340 points (Table 1-2).

Site	Mirak	Chah-e Jam	Bandepey	Kuhrang	Mehran Plain
Number	182	72	29	23	34

Total	**340**

Table 1-2. The number of Iranian Middle Paleolithic points that were selected to analyze micro-fractures.

We compare the morphological characteristics of points in five Iranian sites with several areas inside and outside Iran, where their information has been published. In addition to diagnostic of spear point use, another purpose of studying morphological features is to compare possible symmetry changes in the line of morphological changes in points from the Middle to Late Paleolithic period to make more effective weapons if macro-traces confirm their nature. In other words, it seems that morphological features and their proportion in different groups underwent fundamental changes, leading to geometric balance, improved symmetry, and ultimately more accurate projectile targeting. Understanding these changes and proportions is one of the aims of the paper.

Thus, the morphological features related to the point's aerodynamics were measured in the Iranian sites and compared with other Paleolithic sites outside Iran. These sites include Tor Faraj (70-50k Ka) in Southern Jordan (Groucutt, 2014), Kathu pan1 (291 45) in southern Africa (Wilkins and Chazan, 2012), Kebara (60-50 Ka), Hayonim (100-90 Ka), and Qafzehin (100-90 Ka) Levant (Shea, 1988), and also Sibudu, Rose Cottage in the Middle Stone Age in Africa and Bouheben in the Middle Paleolithic of the southwestern France (Lenoir, 2006), some dart and arrowhead of the collections of the American Museum of Natural History (AMNH) (Thomas, 1978), and finally, the points of the Neolithic sites of Levant (Gopher, 1994). Table 2 summarizes the number of points mentioned above chosen for comparative analysis. These sites were not selected at random because the main aim of the selections was to cover an extensive period. On the other hand, we selected sites where the researchers measured the morphological features of the lithic points, so it was possible to compare the features.

The Middle Paleolithic sites (Groucutt, 2014**;** Shea, 2006)

Site	**Tor Faraj**	**Tabun**	**Skhul B**	**Kebara**	**Rosh Ein Mor**
Number	107	80	27	239	102
Total					**555**

The Middle Stone Age (MSA) in Africa (Villa and Lenoir, 2006**)**

Site	**Sibudu**	**Rose Cottage**	**Bouheben**
Number	125	43	95
Total			**263**

The Upper Paleolithic sites (Thomas, 1978)

Site	**AMNH**
Number	128
Total	**128**

The Levantine Neolithic site (Gopher, 1994)

Site	**El-Khiam**	**Helwan**	**Jericho**	**Byblos**	**Amuq**	**Ha-Parsa**	**Nizzanim**	**Herzilya**
Number	274	1265	1398	1934	1160	371	341	43

Total	**6786**

Table 2. Non-Iranian Paleolithic and Neolithic points

It is worth mentioning that, in this research, except for symmetry, measurement methods applied are those used previously to measure the lithic points of sites out of Iran (Groucutt, 2014; Hardy et al., 2013; Rios-Garaizar, 2016; Sisk and Shea, 2011). In addition, the one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of TCSA or other morphological features such as weight, length, and TCSP to compare the throwing power of the points.

3. Results

We measured the symmetry deviation of all 280 lithic points in the Middle Paleolithic sites of Iran, including Mirak, Chah Jam, the Mehran plain, Koohrang, and Bandpay, separately with a three-dimensional technique (Tables 3, 4). As mentioned earlier, each lithic point was adjusted to its mirror position to measure the deviation from the symmetry of the two sides of each lithic point relative to the highest axis of the tool. Because the two sides of the lithic point are not perfectly symmetrical in all three dimensions, including the proportion of preparation removals and thickness, there is always a degree of deviation identified as positive or negative. The positive deviation is related to the protrusion of most preparation removals of one side of the lithic point relative to the opposite side along the highest axis. In contrast, the negative deviation is the opposite of this. So, more preparation removals lead to more indentation and negative deviation. In this way, the average deviation from the symmetry of all lithic points was calculated separately in each site. Then, the maximum, minimum, and average of their positive and negative deviations were recorded for each site, and using statistical methods, the difference in the mean deviation from their symmetry was compared in the five sites. Table 4 presents the summary statistics for all sites. Considering all the evidence (Tables 3), it seems that all five sites have a large number of symmetrical points and a small number of asymmetrical ones compared to the total number of points that were studied on each site. We recorded 25 asymmetric points in the Iranian sites. Figure 3 shows the mean of deviations in these sites. The result is then compared with six sites outside Iran in the 2D method, enclosing at a quadrat without calculating the I.D.S. The reason for using the 2D method for other sites is the lack of access to 3D images.

site	Variable	n	dmax1	dmax2	dvag1	dvag2	RMS
Mirak	Mean	133	2.88	−2.81	0.70	−0.69	0.89
	Std. deviation	133	0.28	0.39	0.24	0.29	0.38
Chah-e jam	Mean	48	2.77	−2.72	0.67	−0.64	0.89

	Std. deviation	48	0.38	0.42	0.27	0.25	0.38
BandePey	Mean	23	2.6	−2.7	0.9	−0.8	1.10
	Std. deviation	23	0.6	-0.6	0.4	-0.6	0.4
Mehran Plains.	Mean	30	2.3	−2.34	0.70	−0.67	0.92
	Std. deviation	30	0.46	0.47	0.25	0.26	0.27
Kuhrang	Mean	21	2.7	−3	0.87	−0.86	1.1
	Std. deviation	21	1.3	0.52	0.26	0.3	0.27

Table 3 . Summary of deviation analysis of our Iranian site: Dmax (+), the largest positive difference between two surfaces; dmax (−), the largest negative difference between two surfaces; dvag (+), mean the positive difference between two surfaces; dvag (−), means the negative difference between two surfaces; RMS, root mean square of deviation.

site	Number	Mean	Standard deviation	Proportion of unsymmetric/symmetric points
Mirak	133	0.89	0.3	0.15
Chah-e jam	48	0.87	0.25	0.2
BandePey	23	1.09	0.3	0.2
Mehran Plains.	30	0.86	0.3	0.2
Kuhrang	21	1.1	0.45	0.09
Total	225			

Table 4. Descriptive statistics of the symmetry of lithic points in five sites in Iran

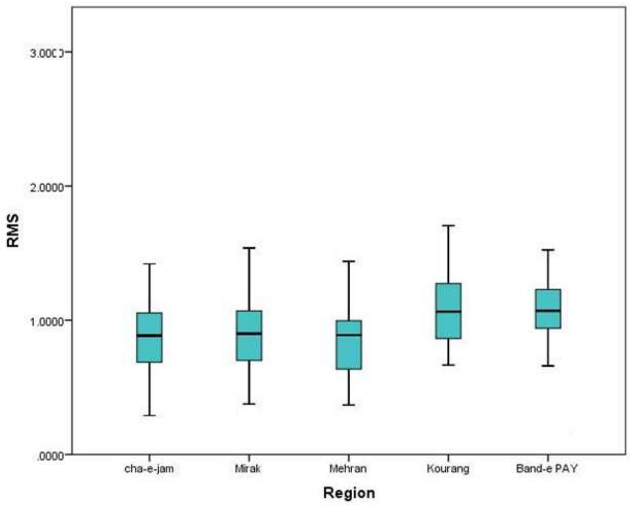


Figure3. Boxplots comparing the mean of deviations in all sites

In the second step, out of 340 points, 9 points did not have a macro trace, and the rest had at least one fracture. Figure 4 presents the results obtained from the analysis of macro-fractures. We determined the nature of the types of fractures, depending on the location of the initiation and termination. For example, it is apparent from this chart that the scars initiated from an earlier fracture surface and terminated on a surface created more than 30% of spin-offs on Iranian data. However, scars initiated from a surface and terminated on another surface created less than 50% lateral removal. In addition, the type of fracture groups and the location initiation and termination create types of burination (Fig.4). Fig 5 shows various types of fractures in Iranian points.

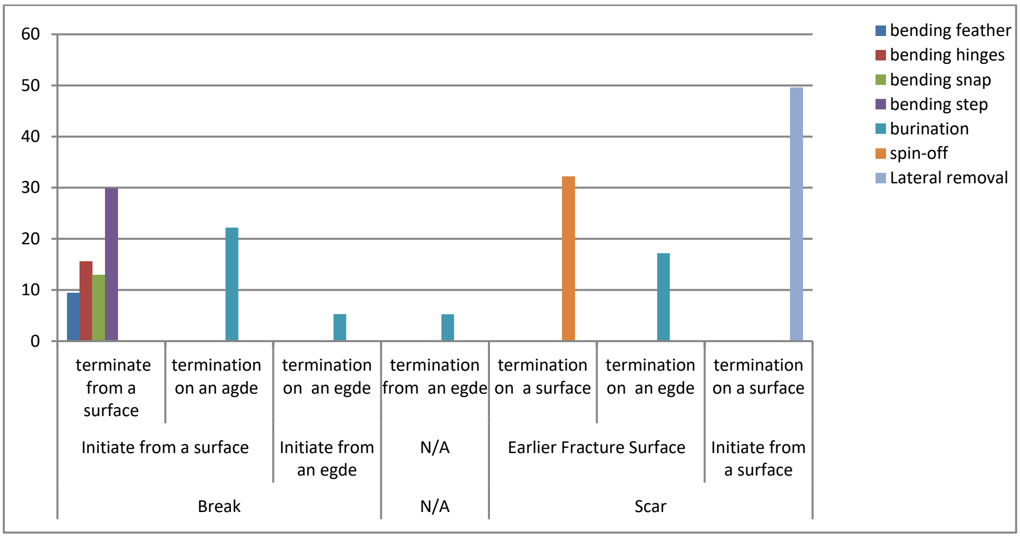


Figure 4. Iranian Paleolithic points: distribution of the traditional diagnostic impact fracture groups compared to the groupings based on the refined attribute system

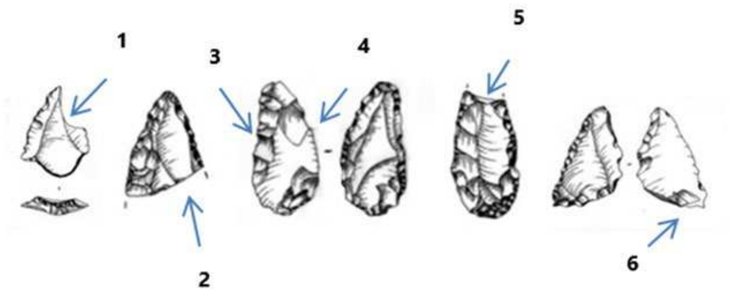


Figure 5. Iranian Paleolithic points:1. Burination 2. bending Snap. 3.Bending step.4. Bending hinge 5 bending feather 6. Spin - off

Table 5 shows the types of termination for bending initiated fractures. In addition, the frequency percentages of fracture types and fracture locations for symmetric and asymmetric points have been calculated separately (Fig. 6). The aim is to find a significant connection between a/symmetrical points and their functions. In this regard, up to 40% of symmetrical points fractures are at the distal, whereas more than 30 percent are at the armatures' mesial. In contrast, the fractures of asymmetrical points have an opposite pattern. Most of the fractures are located in the mesial part (fig. 7). However, hinge, snap bending, and spin-offs are seen more frequently in asymmetrical points, whereas feather and burination fractures have a smaller percentage.

Type of termination	Percentage and number
feather	9.4% (24)
hinges	13.4% (34)
Snap	18.1% (46)
Step	19.7% (50)
Complex termination	39.4% (101)
Total	100%

Table 5. Proportion of the types of termination for bending initiated fractures in Iranian points

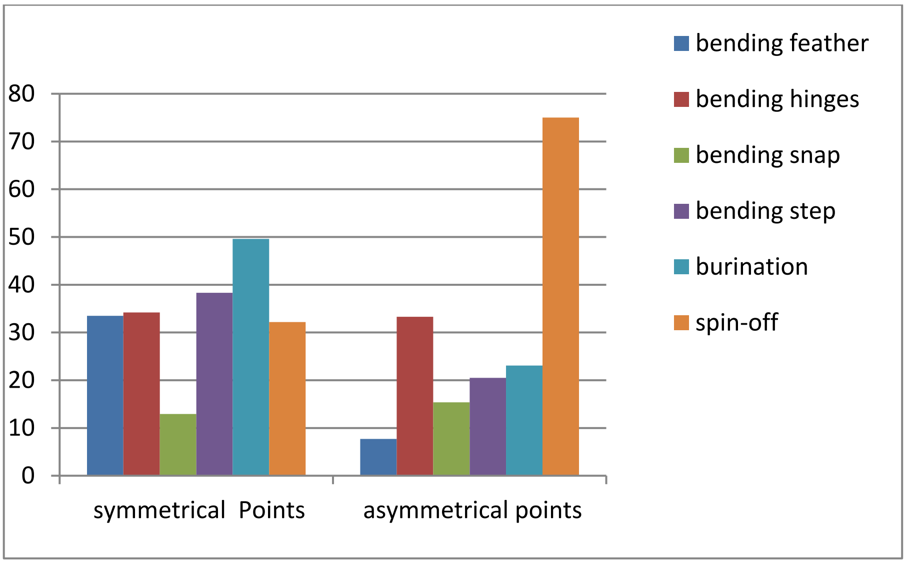


Figure 6. Iranian Paleolithic points: Distribution of the traditional diagnostic impact for symmetric and asymmetric points

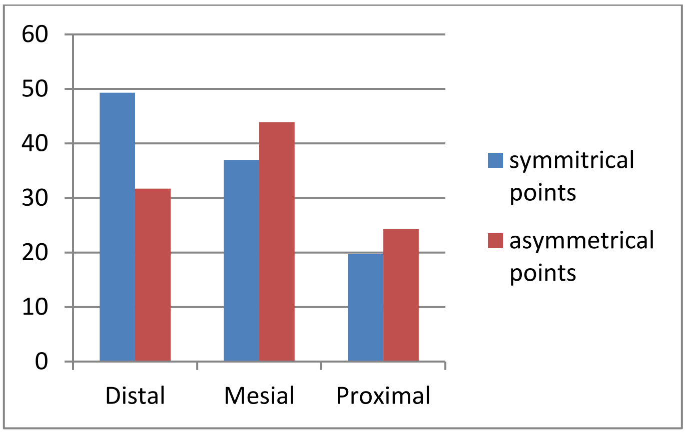


Figure 7. Iranian Paleolithic points: location of the damage in Iranian points

In the third stage, as can be seen from Appendix Table 1-1, 2, and Figure 8, the means of morphological features in Tor Faraj are comparable with those of the Iranian sites; these tables present the summary statistics to compare the lithic points of Middle Paleolithic sites of Iran and Tor Faraj. Regarding size, sites such as Khuhrangh and Bandepay usually have larger lithic points than Tor Faraj and other Iranian sites, including Cha-e Jam, Mirak, and the Mehran Plain. Nevertheless, the elongation of all Iranian points is smaller or equal to Tor Faraj's points. In other words, despite the large weight, area, volume, TCSA, they have little elongation. However, the Sibudu, Rose Cottage, and Bouheben's points are less elongated, despite being comparable in height to Iranian and Tor Faraj's points.

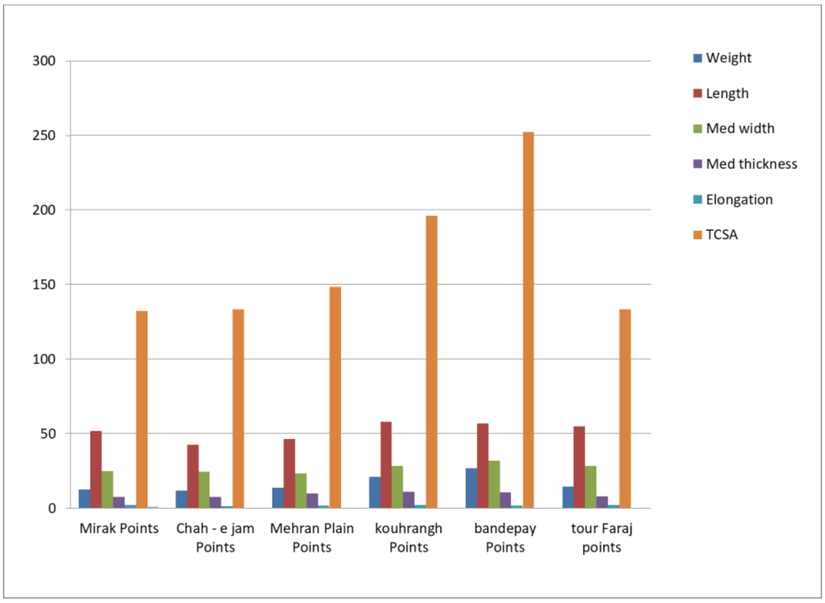


Figure 8. Comparison of morphological features of Mirak, Chah e jams, Mehran Plain, kouhrangh, bandepay, and tour Faraj points

According to these morphological features, we believe that Iranian points do not have the capacity of throwing. The experimental use of hand-made points similar to Mirak's points proved this claim (Mehrpoor Moghadam, 2009). Based on the thesis, a point was constructed with the average morphological features of Mirk points. This point was attached to three hafts with different weights of 500 g, 800 g, and 1200 g and was thrown to a lamb meat several times. The launches were done from different distances 10m, 8m, 6m, 4m, and 2 m. These spears did not penetrate despite the contact with the muscle, these spears did not penetrate, and only a scratch effect was seen (Mehrpoor Moghadam, 2009).

Based on the above results, one reason for this could be the lack of the ability to create perfect symmetry in the points, and insufficient elongation due to the proximity of length and width values is the main factor in increasing the drag and decreasing penetration depth. On the other hand, being approximately equal in width to the length of the arrowhead is the main factor in their durability (Van Buren, 1974). However, based on the Mummy Cave tip, Hughes shows a trade-off between increasing penetration depth and durability (Hughes, 1998). She believes most projectiles were designed to increase penetration, so unlike the thrusting spears, they were less durable (Hughes, 1998). The South African Middle Stone Age points in Sibudu, Rose Cottage, and the Middle Paleolithic points in the South West of France support this claim (See Table 6).

Site	Length (mm)	Width (mm)	Thickness (mm)	Weight (gm)	TCSA (mm2)	Elongation	Flattening
Bouheben	57.4	32.1	10.7	18.9	177	1.8	3
Sibudu, final MSA	46.9	27.7	7.3	10.7	116.2	1.7	3.8
Sibudu, RSp-MOD	41.8	27	8.1	11.9	117.7	1.6	3.3
Sibudu, layers below RSS	45.3	28.7	9.6	14.2	139.4	1.5	3
Rose Cottage	36.6	21.4	7.1	5.2	74	1.7	3

Table 6. The morphological measurements for spear points from Sibudu, Rose Cottage.and Bouheben in the Middle Stone Age and the Middle Paleolithic (Villa and Lenoir, 2006)

Homo sapiens probably produced darts systematically and extensively during the Upper Paleolithic, and the arrowhead as a weapon was associated with the darts (Shea, 2006), although later replaced it (Hughes, 1998). Some scientists believe that making throwing weapons eventually enabled Homo sapiens to leave out of Africa and enter temperate western Eurasia (Shea and Sisk, 2010).

Shea is among the archaeologists who believe that cross-sectional area is a vital factor in the ballistic power of the weapon (Shea, 2006). Statistically, Shea shows that the TCSA values of the points are significantly different between the two types of stone projectile points (spear-thrower dart tips and arrowheads) and spear points. He obtained this result by comparing the TCSA values of stone projectile points to the Middle and Upper Paleolithic stone projectile points from Africa, the Levant, and Europe. Aerodynamically, at the moment, it is evident that a perfect projectile has an optimal shape. However, the question stands: what morphological changes caused such a success in the Upper Paleolithic points?

In 1976, Thomas measured 128 projectiles including 10 darts and 118 arrowheads. Following this, several archaeologists used this set to find correlations or differences with data from different regions (See Hughes, 1998 & Shea 2006, Shea and Sisk 2010, Sisk and Shea, 2011). In line with our research, we also need to know whether or not any differences of importance existed between the mean TCSA in our middle Paleolithic points with Thomas's projectiles. We tested this possibility with an ANOVA (one-way). The calculated value of F was 41.46, and the significance level was S = 0.000. Therefore, the null hypothesis is rejected, suggesting that the difference between the TCSA means is significant. Results of the ANOVA further indicated a need to compare the mean of TCSA for all sites. The least significant difference (LSD) test helps identify the TCSA whose mean is statistically different. Results of the LSD tests indicate that Thomas's projectiles have a statistically significant difference from our Iranian points, although darts and arrowheads do not differ from each other significantly (Fig. 9). Thus, our Iranian middle points have larger TCSA than Thomas's darts and arrowheads.

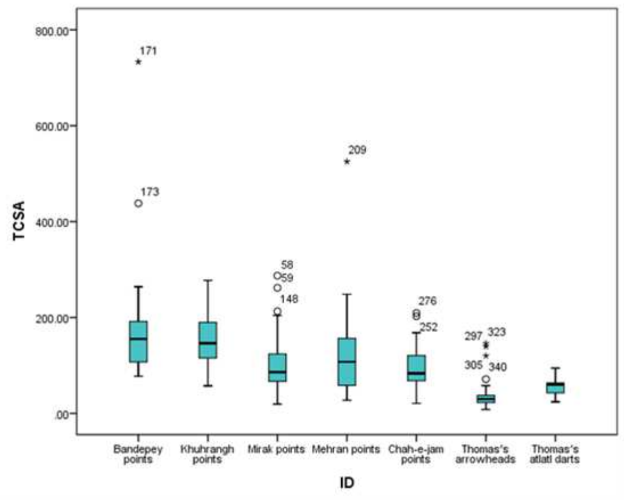


Figure9. Comparison of TCSA of Mirak, Chah e jam, Mehran Plain, kouhrangh, bandepay, and Thomas's Dart and arrowhead

In addition, we calculated the means of other morphological features measured by Thomas. As can be seen in Table 7, the darts have been taller, thicker, and have wider tips than the arrowheads, whereas all of them are much lighter than the Middle Paleolithic points. However, elongation and flattening are approximately equal (Appendix Table 1-1, 2, and 8). In addition, arrowheads have shorter and smaller (in diameter) fore shafts than the darts.

As shown in Table 9, in the Neolithic Levant sites, the projectile points have the same average length as the Middle and Upper Paleolithic points. In contrast, they have less width and thickness. It should be noted that we calculated the means of morphological features of the Levantine points that were published by Gopher (1994).

Tools	n	Length (mm)	Width (mm)	Thickness (mm)	Neck Width(mm)	Weight (gm)	TCSA (mm2)	Foreshaft (mm)
Dart	10	46.2	22.9	4.9	13.7	4.38	56	105
Arrowhead	132	31.1	14.7	4	10	2.07	33	71

Table 7. The morphological measurements for arrowheads and dart tips Tomas's sets

Tools	n	Elongation	Flattening
Dart	10	2.02	4.7
Arrowhead	132	2.12	3.7

Table 8. The measurements of elongation and flattening for arrowheads and dart tips

sample	Length (mm)	Width (mm)	Thickness (mm)	TCSA (mm2)	Elongation	Flattening
Helwan points	32.41	9.4	3.1	20	2.5	4.2
Jericho points	52.04	14.4	4.3	31	3.6	3.3
Byblos points	49.83	13	4.1	27	3.8	3.2
Amuq points	52.85	12.3	4	26	4.3	3.1
Ha-Parsa points	28.8	11.2	3.3	18	2.6	3.4
Nizzanim points	31.83	10.9	3.6	20	2.9	3.03
Herzilya points	28.24	12.2	3.7	23	2.3	3.3

Table 9. The morphological measurements for the arrowheads of the Neolithic Levant (Gopher, 1994)

Discussion and Conclusion

In Iranian data, burinations fractures are common (Fig. 4, 5). Based on the attribute-based approach, one of the common ones is a scar initiated from an earlier fracture surface as a cone initiation and terminated on edge (Coppe and Rots, 2017). For example, proximal corner fractures are an essential part of Iranian symmetrical points. These fractures have been first determined using Clovis points' experimental use as thrusting spears (Huckell, 1982: Fig. 2a, 2a´). Huckell (1982) shows that a slight lateral pressure exerted on either the spear shaft or the projectile point might cause these fractures. However, Odell believes that forces oriented directly through the point's body probably cause cone initiations that lead to the formation of lateral macro fracture (Odell, 1981). Interestingly, complex termination has the most significant proportion between the types of termination, which are primarily formed in the distal parts (Table 5).

Let us now turn to the symmetrical and asymmetrical points, Based on the distribution of the traditional diagnostic impact fracture groups. There are types of fractures characteristic of the weapon's tip that can be seen in symmetric and asymmetrical Iranian data, including burin-like fractures, hinged, step, and feather terminating bending spin-offs. These fractures are seen alone or in combination with each other. In all sites, especially Mirak and Cha-e Jam, lateral snapping or "a mesial breakage are prevalent"; Shea described this breakage in the Middle Paleolithic points of the Levant and experimental spear/projectile points (Shea, 1988, 2002). Both hinge step and feather terminations after burination have a considerable frequency in symmetrical points. These bending fractures were common throughout the projectile and were determined on Levallois points from several Levantine Mousterian sites (Shea 1988, 1991). In addition, as Caspar and De Bie (1996) show, these bending fractures and burination were related to hafting technique.

About the place of distribution, the contribution of the mesial part of the asymmetrical points to snap bending fractures is more than symmetrical. In contrast, symmetrical points are damaged with burniation and then step terminating bending. Hinge terminating bending in both is approximately equal.

Based on Coppe and Rots approach (2017), on the one hand, a strong correlation exists between the fracture of distal parts and contact with a bone and between the fracture of mesial parts and skin-gelatin contact. On the other hand, a relation exists between spin-off's and bending hinge-terminating fractures and contact with skin – gelatin. However, they could not show a direct link between the mode of propulsion and the location of the fracture (Coppe and Rots, 2017). Accordingly, comparing the fracture location in symmetrical and asymmetrical points in Figure 6, it can be said that symmetry can probably be an important factor in the penetration of a weapon into the target.

The third dimension of the lithic points is a critical factor in creating symmetry. It is necessary but not sufficient to have a two-dimensional symmetry (length and width), although the third dimension seems determinative. It means that in addition to symmetrical appearance, realistic symmetry is also necessary for the useful function of a lithic point (Feizi et al., 2019).

Thus, both sides of the lithic point must be in similar conditions regarding the removal depth. Despite the existence of a symmetrical appearance, some lithic points do not have realistic symmetry (Fig. 10). Our previous studies show that the more conscious the attention is, the more regular the pattern of point preparation removals is (Feizi et al., 2018) (Fig. 11).

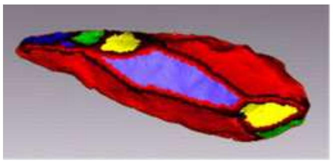


Figure 10. The symmetrical point with a regular pattern in terms of ridges and troughs (Areas of the same color have the same depth and) prominence (Feizi et al., 2018).

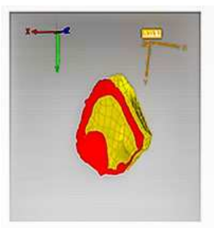


Figure 11. The unsymmetrical points (The dorsal side of the CAD (golden color) and mesh (red color) models overlap) (Feizi et al., 2018)

Overall, there is a significant relationship between sites and the degree of deviation from symmetry (see Feizi et al., 2019). The sites can be divided into two groups in regard to this degree of deviation. Points in group 1, which includes Mirak, Chah-e jam, and Mehran Plain, are more symmetrical than those in group 2 (Kuhrang, BandePey). In addition, retouch had a key role in achieving and modifying symmetry. In all sites, retouch was used for achieving symmetry of the edges and shaping the lithic points, particularly in group 1 (Table 10). To sum up, a common pattern of deviation from symmetry is apparent in each group, and this suggests a difference between groups in the amount of conscious attention which can be the result of access to raw materials (Feizi et al., 2019). However, research shows that retouched point is related to their penetration ratio (Odell and Cown 1986 & Sick and Shea, 2009). Odell and Cowan (1986) consider this relationship to be positive.

site	N	Means	Std
Mirak	148	4.02	0.14
Chah-e jam	58	5.18	0.18
BandePey	27	3.4	0
Mehran Plains.	31	4.66	0.19
Kuhrang	23	3.09	0.26

Retouched points are more durable and slightly more effective than unretouched points (Odell and Cowan, 1986), while experimental studies of Sisk and Shea show more penetration rates belonging to unretouched points due to retouching increases drag (Sisk and Shea, 2009). Width, on the one hand, is a critical factor in increasing drag (Hughes 1986), and more width, resulting in more drag, is an advantage for a hand-cast spear or thrusting spear. Our Iranian points, especially those in group 2, have more width than the upper Paleolithic point and are more suitable for the thrusting spear. In addition, BandePey and Kuhrang's points, group2, have a low percent of retouch, while the analysis of macro-fractures is not significantly different between the two groups. It seems that all these points are so broad, or in other words, they are on the threshold of width, performing the same action. On the other hand, Sisk and Shea (2009) believe that there might be a threshold for decreasing the effect of retouching for the use of stone points (Sisk and Shea, 2009).

The quadrangle technique could reveal a similar pattern for deviation of symmetry in the Middle Paleolithic points. It seems likely that Neanderthals did not attempt to create specific symmetrical tools. In another way, they have been convinced of general symmetry (Feizi et al., 2019). When these lithic points are located in the quadrangle that measures the deviation of symmetry, the axis is passing the left or right shoulder. Therefore, the highest axis of symmetry is parallel or makes an angle. In a similar vein, when the axis of symmetry crosses over the midline, the two sides of points do not have similar morphology (Fig. 12 -1, 12 - 2, 12 - 3). They also used lithic points with larger TCSA to make projectile points only for close hunting (Shea, 2006).

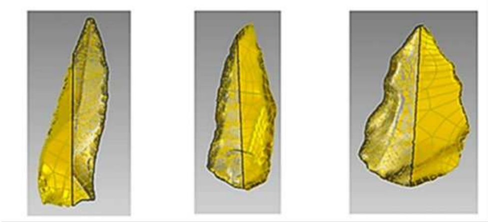


Figure 12-1. In the middle Paleolithic, hominids had not carefully performed symmetry (Feizi, 2018).

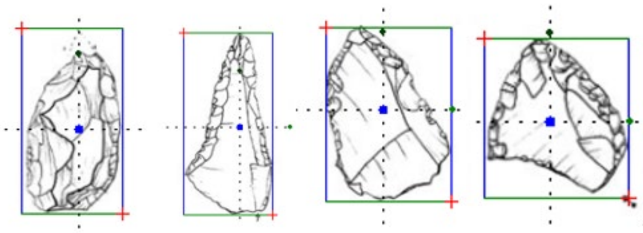
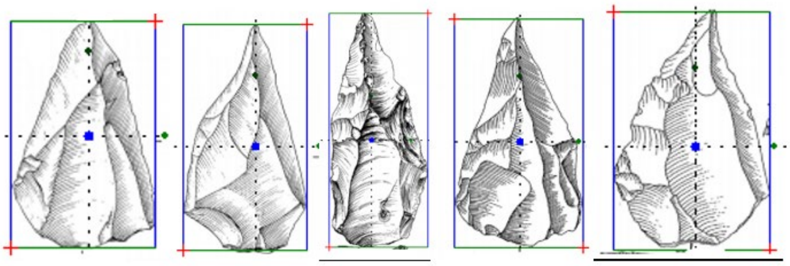


Figure 12-2. The deviation from symmetry in the Northern Iberian Peninsula MiddlePaleolithic Mousterian Point (Rios-Garaizar, 2016)



1 2 3 4 5

Figure12-3. Examples of Middle Paleolithic points from northeast Africa and southwest Asia, 1, 2: Jebel Katefeh, 3. Aybut al Auwal, Oman. 4, 5: Nazlet Khater, Egypt (Groucutt, 2013)

In general, the situation looks completely different in the Upper Paleolithic. The study of projectile points of the sites mentioned above in Iran (Yafteh cave, Arjaneh, Boof cave, Galeh ghosheh site) shows that a serious change has been made in the administration of symmetry in the Upper Paleolithic points (For example, Fig. 13).

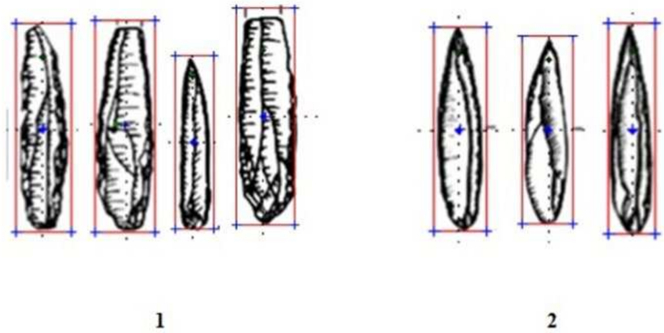


Figure 13. Several symmetrical projectile points (Arjaneh point) in 1. Qaleh Gosheh 1(Conard, et al., 2009), and 2. Yafteh cave (Hole, 1970)

In addition, the comparison of the Iranian Middle Paleolithic projectile points with those from outside Iran such as Levantine points (Emireh, Umm el Telel, Ksar Akil, El Wad points) (Shea, 2013: 141), the West European points (Chatelperronian, Gravette, Font Robert, Solutrean), Middle Stone Age of Africa (symmetrical triangular flakes, foliate bifaces, unifacial points, tanged points) demonstrate similar patterns.

Using the quadrangle technique for the Upper Paleolithic points indicates that symmetry has evolved to a large extent compared to the Middle Paleolithic period. This is because, as mentioned earlier, when the Middle Paleolithic points are adjusted in a quadrilateral that measures the deviation of symmetry, the axis of symmetry, the line that halves the quadrilateral, is passing through the left or right shoulder. Even if it halves the lithic point precisely, the preparation removals relative to the axis of symmetry are very irregular. This deviation decreases with a positive correlation between the increasing proportion of preparation removals and the decrease in the deviation of symmetry on the two sides of the lithic points (Feizi et al., 2017). In general, according to the more or less identical pattern of deviation from the symmetry of the Middle Paleolithic points in all the studied areas inside and outside Iran and significant differences with the next period, this problem seems to be more cognitive than cultural, including conscious attention. However, conscious attention has changed for various reasons, such as selectivity and the accessibility to raw material, and the skill of the toolmakers.

For Wynn, symmetry has several attributes that link the archeological record and cognitive ability. It is incorporated into many schemes of spatial cognitive development and theories of perception, and in addition, it is perusable to visual presentation.

Handaxes are the first symmetrical artifacts and probably made by Homo erectus (Jones, 1981; Wynn, 2002). The symmetrical structure of Acheulean bifaces leads to tracing the cognitive evolution of Homo species in the bifaces (Hodgson, 2015). However, what is interesting in the artifacts is that Handaxes by themselves had a two-stage progression (Wynn, 2002). The first step was a general two-dimensional shape in early handaxes. The second development was the appearance of reflectional symmetry in three dimensions, both in profile and in plan and in cross-sectional view, as a sectioned oblique to the principal axes (Wynn, 2002). Although many bifaces do not have it, there is a significant deviation from 3D symmetry in these symmetrical bifaces. Symmetry in all three dimensions or realistic symmetry is required for the second symmetric tool, the points. The reason is that morphological features and macro fracture show they must have much more refined symmetry for finer ballistic control.

Interestingly, it seems that *Homo sapiens* paid special attention to the practical aspects of symmetry. Accordingly, they made the symmetrical points where the axis of symmetry generally crosses over the midline and its two sides have the same morphological figures and thickness (Fig. 14). Although there are many asymmetrical points at this time, it seems that increasing the cognitive capacity of symmetry implementation led to making a perfect projectile since the Middle Paleolithic period. In the Upper Paleolithic period, all points were not projectiles or spear points; they might be knives or have other functions (Newman and Moore, 2013). Therefore, not all of the Upper Paleolithic points need to have optimal symmetry. However, as outlined earlier, perfect symmetry is impossible in reality, and there is always a numeric value as the deviation of symmetry.

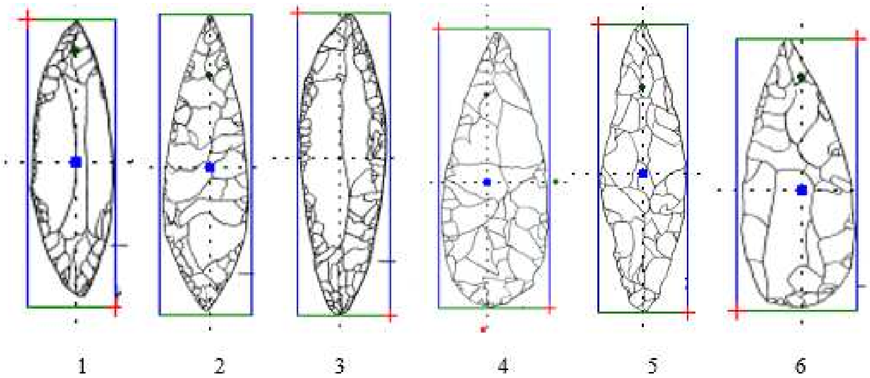


Figure 14. The samples of the upper Paleolithic points in Europe: (1) small Solutrean unifacial point (Roc de Sers, France), (2) Solutrean bifacial point (Founeau du Diable, France), (3) large Solutrean unifacial point (Laugerie-Haute Ouest, France), and southern Africa: (4,5) Still Bay points (Skildergat, South Africa), (6) bifacial point (Porc Epic Cave, Ethiopia), (Shea, 2006).

In the Upper Paleolithic period, it seems that balance and realistic symmetry were created. This is because *Homo sapiens* started to pay attention to the thickness of lithic points. Tool efficiency may explain why *Homo sapiens* focused on making symmetrical points. Unfortunately, we did not have enough projectile points to measure 3D symmetry for the Upper Paleolithic points. However, the indirect documents such as the decreasing thickness, weight, width, and increasing degree of preparation cause optimal symmetry. Hence, we can generally say lithic points derived from blade technology have a higher symmetry than Levallois technology due to their specific morphology (e.g., fewer cross-sections, more elongation) and more uniform blade surface.

Accordingly, we believe that symmetry was evolving in the Paleolithic period, and the deviation of symmetry affected the throwing performance. In addition to symmetry, other morphological features such as elongation, area, weight, and cross-section were measured in this research. In later periods, there seems to be geometric coordination between these elements. Our reason is that the increasing proportion of preparation makes the point surface smoother. On the other hand, improving the proportion between width and length reduces the cross-section. It causes the elongation of lithic points and the development of 3D symmetry. This claim is consistent with Shea and colleagues' experimental studies showing that narrower or longer points such as darts and arrowheads minimize drag and are helpful as the high-speed projectiles (Shea et al., 2001). In addition, Hughes shows that a projectile with a thin, elliptical cross-section similar to a long, lanceolate tip is the most effective penetrating shape, which creates a large hole in the target and is the practical shape for penetration. In addition, she emphasizes the importance of a smooth shape to reduce the drag coefficient. She considers the most efficient form for penetration to be an elongated ellipse, with a smooth surface and a smooth transition to the shaft (Hughes, 1998).

Variation in the armature's morphometric may be have been compensated by variation in shafts and other elements of these composite technologies. For example, Shea and his colleagues have shown experimentally that point symmetry in plan shape should play a role in fracture formation, but the hafting arrangements compensated this (Shea, 2002). Nevertheless, this problem has value within the group, and there is a degree of asymmetry between different groups that affect the amount and accuracy of penetration (Salem and Churchil, 2016). Decreasing deflections is important aerodynamically that lead to the change in foreshaft angle and the shape of point itself (Churchil, 1993). Several morphological changes include increasing penetration relatively small size, greater symmetry about the long axis, basal modification to facilitate hafting, and size standardization of the proximal end(Odell and Cowan, 1986).

The evidence shows that, generally, arrowheads and darts are perfect projectiles (Thomas, 1978). As we can be seen in Table 8, the mean of darts and arrowheads elongation respectively are 2/02 and 2/21 with the cross-sections that respectively are 56 and 33. A simple mathematical proportion proves that if Mirak's points with this mean (=51/9) are projectiles, the means of the elongation will be 3/53 approximately. At the same time, this is equivalent to 1.99 for Mirak's points. On the other hand, as can be seen in Appendix Tables 1 and 2, in the Middle Paleolithic, generally, the cross-section area was not located at the middle length of points; as a result, the drag could not be minimum. Thus, the shape of the trajectory is not standard, and throwing is not distance hunting or executed correctly. However, it should be noted that Thomas's projectiles are ethnographic arrowheads and darts, and many factors contribute to their shape and symmetry, including non-functionality. What is interesting in this data is that in Jericho and Amuq projectile points (Table 9), the Neolithic sites of the Levant, which are about the same length as the Mirak's point, are more elongated and much thinner. Data from Appendix Tables 1, 2, and Table 6 can be compared with Table 9. The result in most Middle Paleolithic sites (including Mirak, Chah-e-jam, Khuhrangh, Bandepey, and Mehran in Iran, and Torfaraj in Jordan and Bouheben in the southwestern of French, and middle Stone Age of Sibudu and Rose Cottage in Africa) is quite contrary. We do not have the lithic points with geometric proportions and enough elongation to overcome the drag in these Middle Paleolithic sites. Based on a t-test, Thomas showed that arrow foreshafts are undeniably smaller (in diameter) than dart fore shafts (Thomas, 1978). However, morphologically, the darts are larger than the arrowheads and have longer fore shafts than arrowheads. This relationship may be due to the created proportion and the throwing power of the points; the subject needs further investigation.

On the other hand, based on experimental data, some researchers have focused on fracture mechanics to identify projectile use and penetrating characteristics (please see Fisher et al., 1984; Odell and Cowan, 1986; Dockall, 1997; Plisson, 2005; Iovita et al., 2013; Rots and Plisson, 2014; Coppe and Rots. 2017). Dockall showed that there are unique fracture patterns of the projectile (Dockall, 1997), resulting from attachment to the handle or the impact of physical contact (Kufel-Diakowska, 2016). Based on these studies and comparing the pattern and location of symmetric point fractures and asymmetric areas of Iran, symmetrical points appear to tear the skin and gelatin and penetrate the bone. On the other hand, asymmetric points become more involved with the skin and gelatin and probably break before contact with the bone. However, it should be noted that haft is very effective in this practice. This is because even in symmetric points, there is still much deviation from symmetry, and the haft must compensate for the morphological shortcomings in lithic points.

The target is also a criterion in ballistic and will significantly affect the results (Rots and Plisson, 2014). Thus, a hard target needs a perfect projectile. Thus, an oblique contact leads to the formation of the mesial scars, whereas an oblique contact itself is a consequence of a deviation of the projectile (spin calibration) (Coppe and Rots, 2017). The deformation and fracture of the target as a contact problem between the target and the projectile is inevitable (Rodriguez-Millan et al., 2018). In addition, one of the most important aspects of the geometric design of a projectile is predicting the penetration depth (Wingrove, 1973). It seems that the penetration depth of an arrow is more than the dart (Hughes, 1987). However, in the thrusting spear, due to the intervention of the hand and the placement of the shaft in hand, the depth of penetration is so great that it penetrates muscle relatively well and then impacts the bone (Shea, 2002), and leads to produce massive damage around the site of impact (Churchill et al., 2009). In addition, experimentally, the spin of an arrow is much more stable than a dart, while an arrow is less likely to hit the target under this angle that will cause a dart to hit the skin under an oblique angle (Coppe and Rots, 2017).

It should be noted that the cross-sectional area, the shape, and the mass-velocity relationship of a stone tip affected its penetration depth (Hughes, 1987). However, in experimental throws on an animal carcass, researchers have showed that in terms of penetration, retouched and shaped points have almost the same performance as unretouched and unformed points (Odell and Cowan, 1986 and Churchill, 1993), although these results are from intragroup points and relate to only certain types of points with almost identical morphology. For Andrefsky, the production of formal tools needed more effort and was usually done when raw material occurring in low abundance or at some distance. Proximity to raw material leads to the use of lithic tools over a short period because tool makers do not need to exert much effort in producing new tools, nor do they need to save material by making small tools (Andrefsky, 1994). In intragroup points, for example, Middle Paleolithic points in our research areas, retouch was used for achieving symmetry of the edges and shaping the lithic points, particularly in Mirk, Chah Jam, and Mehran plain. In these sites, toolmakers attempted to reduce the deviation of symmetry using retouch. So, in the three sites, the relatively great distance to the raw material sources required saving raw materials and manufacturing formal and symmetrical points (Feizi et al., 2019). During the evolution of the point, more symmetrical points improve projectile precision and flight dynamics (Churchill, 1993). Following such research, experimental studies of Salem and Churchill (2016) show that "the asymmetrical points were also more likely to possess protrusions and other irregularities that would be expected to increase drag, which may have contributed to the lower average, and penetrated the depth of these points relative to the symmetrical stone points." They show that more symmetrical points have a more regular flight path than very asymmetric points. So, mass imbalance at the distal end of the projectile or shape asymmetries at the tip leads to an erratic flight path (Salem and Churchill, 2016). In addition, the more symmetrical point has fewer protrusions (Feizi et al., 2019), which causes a decrease in the drag coefficient and an increase in its penetration depth (Hughes, 1987). Accordingly, it seems that (2017), the realistic symmetry and more regular flight trajectories of an arrow causes a reduction in its spin and deflection and a decrease in the oblique contact with the target. It seems that this can explain why the deviation of symmetry, other morphological features, and fractures indicate that Iranian points need haft and hand delivery to move correctly.

In sum, macro-fractures analysis, measurement, and comparison of morphological features alongside our mathematical method convinced us that significant changes had occurred in the morphology of points since the Middle Paleolithic period. Some morphological changes, such as the slightest deviation of symmetry and the proportion between width–length and width-thickness that could be among the drag reduction factors, occurred in the Upper Paleolithic. Accordingly, in the Middle Paleolithic period, the minimal number of lithic points may have such features. In contrast, we think that the points gradually have become projectile points for better survival of Homo sapiens. Most of all, this development could be the cognitive development of Homo and, in particular, modern humans.

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Appendix

retouched Mirak points	**n**	**Mean**	**S.d**
Weight (g)	143	12.7	7.6
Area	143	1253	468.5
Length (mm)	143	51.9	10.7
Width at med (mm)	143	24.7	6.4
Max width (mm)	143	28.4	8.1
Thickness at med (mm)	143	7.5	2.5
Max thickness (mm)	143	9.2	4.5
Volume (mm3)	143	14134	8422.5
Elongation	143	1.99	0.8575
Flattening	143	3.4	1.04
Platform flattening	143	3.4	1.4
Relative platform size(mm3)	143	185.1	118.9
TCSA	143	132.3	65.1
retouched in Chah-e-jam points	n	Mean	S.d
Weight (g)	57	11.9	7.2
Area	57	1055.4	481.3
Length (mm)	57	42.6	10.4
Width at med (mm)	57	24.6	5.5
Max width (mm)	57	28.2	6.6
Thickness at med (mm)	57	7.6	2.3
Max thickness (mm)	57	9.13	4.3
Volume (mm3)	57	12261.9	8500.5
Elongation	57	1.5	0.3
Flattening	57	3.3	0.9
Platform flattening	57	3.4	1.2
Relative platform size(mm3)	57	196.5	110
TCSA	57	133.5	62.3
Retouched Khuhrangh points	n	Mean	S.d
Weight (g)	22	21.1	10.5
Area	22	1719.3	518.3
Length (mm)	22	57.9	9.12
Width at med (mm)	22	28.4	5.04
Max width (mm)	22	28.3	8.04

Retouched Khuhrangh points	n	Mean	S.d
Thickness at med (mm)	22	10.9	3.06
Max thickness (mm)	22	15.6	9.6
Volume (mm3)	22	23221.1	10759.7
Elongation	22	2.3	0.9
Flattening	22	2.3	1.1
Platform flattening	22	2.7	0.9
Relative platform size(mm3)	22	268.8	119.9
TCSA	22	195.9	65.09
Retouched Bandepey points	n	Mean	S.d
Weight (g)	27	26.7	21.6
Area	27	2060.3	989.6
Length (mm)	27	59.6	15.6
Width at med (mm)	27	31.9	9.4
Max width (mm)	27	37.5	10.7
Thickness at med (mm)	27	10.7	3.9
Max thickness (mm)	27	12.9	3.7
Volume (mm3)	27	33422.2	30027.2
Elongation	27	1.63	0.32
Flattening	27	2.9	0.74
Platform flattening	27	3.02	1.2
Relative platform size(mm3)	27	360.4	223.6
TCSA	27	252.2	133.1
Retouched Mehran points	n	Mean	S.d
Weight (g)	31	13.9	10.5
Area	31	1235.3	604.7
Length (mm)	31	46.3	12.04
Width at med (mm)	31	23.4	7.2
Max width (mm)	31	27.08	7.8
Thickness at med (mm)	31	9.9	5.4
Max thickness (mm)	31	10.25	3.3
Volume (mm3)	31	15286.1	11351.1
Elongation	31	1.8	0.38
Flattening	31	2.7	0.7

Retouched Mehran points	n	Mean	S.d
Platform flattening	31	2.5	0.92
Relative platform size(mm3)	31	180.4	121.1
TCSA	31	148.3	80.1
Unretouched points	n	Mean	S.d
Weight (g)	6	10.1	7.8
Area	6	1013.8	474.6
Length (mm)	6	42.4	7
Width at med (mm)	6	23.5	7
Max width (mm)	6	24.5	8
Thickness at med (mm)	6	8.2	2.9
Max thickness (mm)	6	13.3	12.7
Volume (mm3)	6	12747.9	9453.2
Elongation	6	1.9	0.9
Flattening	6	2.8	1.2
Platform flattening	6	3.4	0.98
Relative platform size(mm3)	6	149.3	56.1
TCSA	6	140.5	82.4

Table 3. Descriptive statistics for Levallois point morphology on sites inside Iran.

retouched Tor Faraj points	**n**	**Mean**	**S.d**
Weight (g)	107	14.4	8.5
Length (mm)	107	54.9	13.4
Width at med (mm)	107	28.2	7.4
Max width (mm)	107	37	9.8
Thickness at med (mm)	107	7.9	2.3
Max thickness (mm)	107	7.9	2.3
Volume (mm3)	107	10788.4	7123.5
Elongation	107	2.0	0.6
Flattening	107	4.7	1.2
Platform flattening	107	6.1	2.1
Relative platform size(mm3)	107	8.9	5.9
TCSA	107	133.4	73.1

Unretouched points			
Weight (g)	90	13.8	8.4
Length (mm)	90	53.9	13.4
Width at med (mm)	90	28.0	7.2
retouched Tor Faraj points	**n**	**Mean**	**S.d**
Max width (mm)	90	36.9	9.7
Thickness at med (mm)	90	6.1	1.9
Max thickness (mm)	90	7.7	2.3
Volume (mm3)	90	10381.0	6699.7
Flattening	90	4.8	1.1
Elongation	90	2.0	0.5
Platform flattening	90	6.1	2.1
Relative platform size(mm3)	90	8.7	0.5
TCSA	90	149.5	72.2
Retouched points			
Weight (g)	17	17.7	11.0
Length (mm)	17	60.5	12.3
Width at med (mm)	17	29.1	8.3
Max width (mm)	17	38.8	10.2
Thickness at med (mm)	17	6.7	2
Max thickness (mm)	17	8.6	2.1
Volume (mm3)	17	12945.4	8979.3
Flattening	17	4.5	1.4
Elongation	17	2.2	0.8
Platform flattening	17	6.2	2.1
Relative platform size(mm3)	17	8.1	3.8
TCSA	17	174.1	76.4

Table 4. Descriptive statistics for Levallois point morphology in Tor Faraj points (Groucutt, 2014).