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Virtual three dimensions reconstruction and isoline analysis of human marks on the surface of animal fossils

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Animal fossils in archaeological sites are closely related to human activities. The environment and human activities, such as hunting-selection, cook process, traditional culture and habits can be partly inferred from the variety of fauna, fragmentation of the bones, and the human marks on bones' surfaces. So far, researches about marks on fossils are few in China, and are mainly observed directly by eyes. Light Microscopes and Scanning Electron Microscopes are also applied to the observation abroad. These methods could provide us a lot of information, but are mainly confined to 2 dimensions. In this paper, we analyze human marks on the surface of animal fossils through three dimensions reconstruction and isoline analysis, which enable us observe and measure in 3 dimensions. This method gives us a lot of information as follows: the formation of the marks, the tools that produced the marks, the cutting edge, movement and micro-abrasion of the tools. Through study of human marks on the surface of animal fossils unearthed from Bailongdong Cave in Yunxi, Hubei Province, we have got the characteristics of the marks, and further deepen cognition of the cutting edge, cutting orientation, cutting sequence, as well as micro-abrasion of tools during the formation of these marks. This is the first to use virtual three dimensions reconstruction in studying the human marks on the surface of animal fossils in China.

ancient human, behavior patterns, marks on the surface of animal fossils, virtual three dimensions reconstruction, isoline analysis

During evolution, ancient human experienced biological variation including brain volume increase, mechanical and morphological changes of the body, as well as a series of behavior patterns changes. Behavior patterns reflect human behavioral adaptation to environment, such as tools making and using, fire using, hunting[1,2]. The protein plays a significant role during human evolution, which is obtained mainly by hunting and sucking marrow. So, animal fossils in archaeological sites contain abundant information about human behavior. The environment and human activities, such as behavior adaptation, hunting-selection, cook process, traditional culture and habits can be partly inferred from the variety of fauna, fragmentation of the bones, and the human marks on bones' surfaces[3]. Some researches have been conducted about human marks, including method and criterion about marks identifying[4], ways of hunting and slaughtering, habit to use left or right hand, etc.[5–7]. The earliest consciously made marks were reported to be from Xinglongdong Cave in the Three-Gorge areas[8].

So far, observations of the marks on fossils are done by eyes, or with some apparatus, such as magnifying glass, light microscopes and Scanning Electron Microscopes. These methods could provide us a lot of information, but there are obvious limitations. We can neither see marks clearly enough nor get good pictures for share by eyes or with magnifying glass when the marks are tiny. Light microscopes and electron microscope could

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magnify marks enough and provide images for share with optical devices like camera lens, but the pictures provided are 2 dimensions rather than 3 dimensions, failing to provide some traits of the marks, such as the producing sequence, the difference between the bottom and wall of the marks, which contains valuable information about human activities and life styles. In this paper, we make 3 dimensions reconstruction of marks on the surface of bones, which enable us to observe and measure the marks in 3 dimensions. These 3 dimensions studies of marks and following isoline analysis are new methods of experimental archaeology, providing us a lot of new information about human behavior and life style.

1 Research and experiment

1.1 The source and characteristics of the sample

Seven hominid teeth assigned to *Homo erectus*, animal fossils, and dozens of stone tools were once unearthed from a human fossil site of Bailong Cave in Yunxi County, Hubei Province of China[9]. Another exploration and probing excavation was carried out at this site by the Institute of Vertebrate Paleontology and Paleoanthropology of Chinese Academy of Sciences from April to September in 2007, with stone tools and fossils with artificial marks on them being excavated[10]. This article will focus on one sample, TN2W2②: 59 (Figure 1a), which was included in the items excavated during this period of time. This sample is a fragment of tubular bone of large mammal with two prominent notches could be inspected on the bone's surface. These two notches, simultaneously represent the shape of acute triangle with the maximum breadth is 3 mm and maximum length 8 mm, share the same size, and are parallel to one another. The distance between them is about 4 mm. The deepest point of both notches lies at the side of the greater breadth. To be convenient, number the left notch A and the right one B on the image of below (Figure 1b—d).

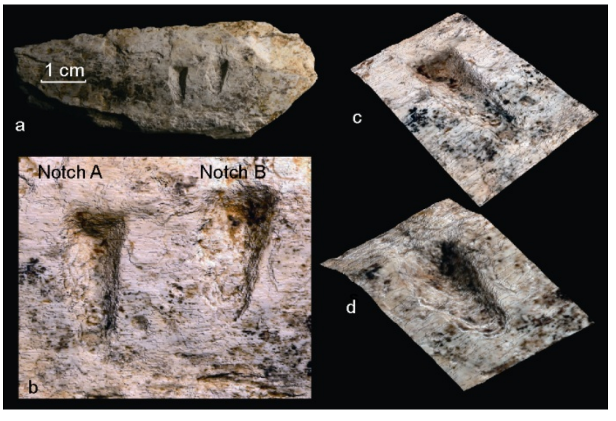

Figure 1 Sample TN2W2②:59 from the site of Bailong Cave and the 3-D digital model of the notches. a, Sample TN2W2②: 59; b, image of digital model of notch A, B when looking down; c, image of digital model of notch A viewed from the southwest; d, image of digital model of notch B viewed from the southwest.

1.2 Construction and detection of the 3-D digital model

Equipment. 3-D contact scanner of Roland, Japan; model: PIX-30/4; scanning accuracy: 0.05mm; subsidiary scan software: Dr. Prza; subsidiary measurement software: AutoCAD2006.

Procedure. Place the sample within the work area of scan device. Scan the notch A, B and their surrounding area, it will last for 18 h before the process of scanning is over, and then, save the data in the format of DXF and input it into the Auto CAD to produce the 3-D digital model, which will be rotated so as to inspect the model from different perspectives. To control the extent to which the model was rotated, we stain the front and back side of the model with different colors respectively (Figure 2). Concluding from the digital model, the front sides of the two notches exhibit similar characteristics, as well as the lateral and back sides. To precisely reflect the characteristics of the two notches, we adopt the method of "three orthographic view" comparison which is usually applied to the three-dimensional images (Take the long axial of the model when looking down as the datum line and adjusted it to be parallel to *Y*-coordinate, we get left-view image from the left to the right and the front-view image from forward to backward).

Results. When looking down, both of the two notches represent 7 turning points along the outlines of the notches (Name them point a1-a2, point b1-b7 respectively). At the bottom (the deepest point) of either of the notches, there is a central striking point (Name them a0, b0 respectively). Under the working page of AutoCAD, the comparison of straight distances and angles between different turning points and the distances from the central striking point to any of the 7 turning points were carried out between notch A and B (Figure 3). Viewing from the left of the model, we can inspect 7 turning points (Name them a8-a14, b8-b14 respectively. Figure 3) along the outlines of both of the notches, while two pairs of corresponding turning points (Name them a15-a18, b15-b18 respectively. Figure 3) could be in-

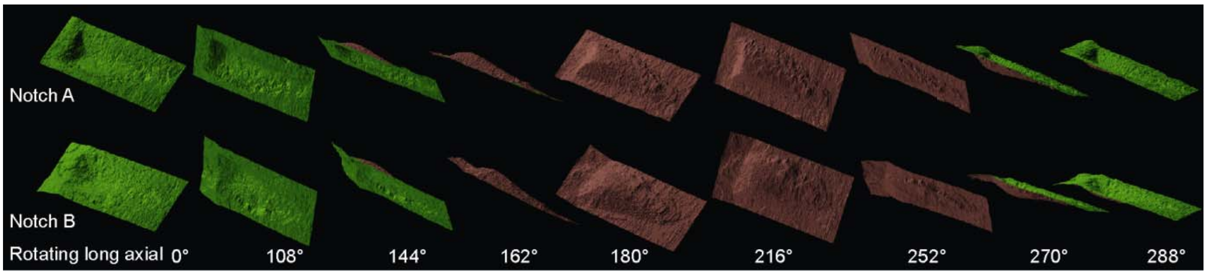

Figure 2 Comparison observation of DYNAMIC of the 3-D digital model of the notches (Notch A and B on the surface of the sample TN2W2②: 59 from site of Bailong Cave).

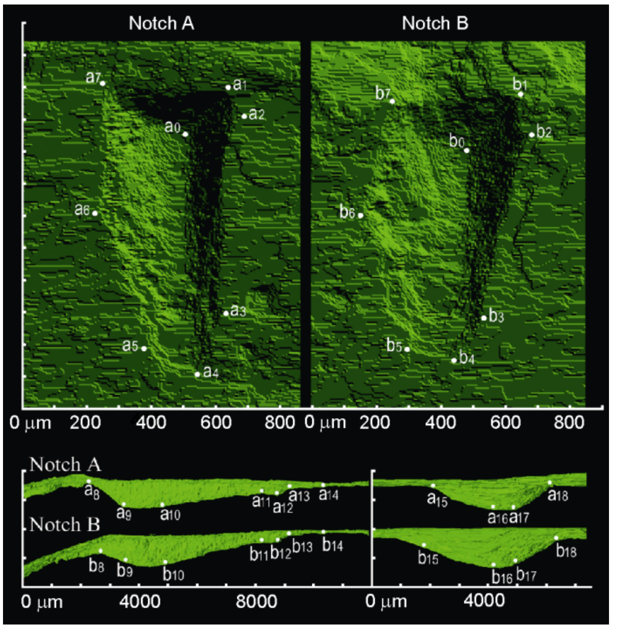

Figure 3 Calculation and measurement of the three-dimensional digital model (Sample TN2W2②: 59 from site of Bailong Cave).

spected on each of the two notches when viewing from the front.

Through the three-perspective view of the models and comparison of their construction, it is concluded that notch A and B share some similarities and at the same time, they have some differences from each other. Similarities: the area of the notch, turning points along the outline, and the dynamic characteristics of forces are fundamentally identical with each other; along the outline of each of the notches, there are 7 turning points which correspond and share the almost identical positions with those of one another, in addition, the straight distances between the different turning points are close to each other; both of the notches have the shape of approximate triangle with a central striking point and the fundamentally identical depth. Judged from the characteristics as mentioned above, all these two notches might result from continuous forces and movements of the same tool. Differences: the outline is more regular in the notch A than in the notch B, the lines linking different turning points along the outline of notch are straighter than those of notch B, the wall's surface of which is less regular and smooth than that of notch A, this is just because of the fact that the notch B suffered more damage to its surface than notch A. The angle of bottom on the image of left-view as well as the front-view of the notch A is significantly smaller than the corresponding angle of notch B. The turning point of the bottom in the notch B is smoother and rounder than that of the notch A. the micro-difference and data discrepancy in the shape of notches might be a reflection of the forming order of notches. These differences in characteristics as mentioned above imply that the blade of the tools was sharper when the notch A was processed, and became blunt and little damaged after the formation of notch A (Notch A came into being before notch B).

1.3 Observation of the isolines graph of the orthographic projection from the top view of the notches

Isolines of the orthographic projection: under the working page of the Dr. Prza, we one-by-one intercept different-level surface with the same height every certain micro-distance from the lowest point of the notch to the top point on the 3-D digital model as have done before. And then, all the surfaces with the same height are linked together and each of the surface was painted with different colors according to its height to form the graph composed of different isolines.

The enclosed extent of the isolines. Notch A: The series of isolines of blue color ($\leqslant$ 500 μm) are all enclosed and formed several regular acute triangles. The green isolines are enclosed, while the groups of yellow isolines do not enclose on their tops and form the similar turning relations with blue and green isolines respectively. The deepest point lies closer to the shorter side of the triangle. Surrounding the deepest point, isolines al-together exhibit radial shape, which results from the spread of the striking forces when the bone was processed by tool with blade facing down. The non-overlapping radiation of the isolines is clear and natural, which indicates that the notch was formed by one-time striking force of the tool. The distribution of the isolines in the level of plane reflects that the shape of the tool's tip might be a quite regular acute triangle. Judged from the characteristic of the radiation, the central striking point might lie closer to the front of the notch rather than its back, when the long axial of the notch is established as the midline. At the side closer to the central striking point, the edges of the isolines are relatively smooth and straight, its intensity is large, and the extent to which the bone is damaged is small. On the contrary, the isolines are relatively sparse, the radiation is undulated in high degree, and the surface of the bone suffered more damage on the opposite side of the notch.

Notch B: Several sharp triangles are formed by enclosing the blue isolines, with their points relatively round and smooth compared with notch A and their sides exhibiting the shape of arc pointing outside. Isolines above 600 μm are not enclosed. The turning relationship of the series of yellow isolines with the blue and green ones at the bottom of the notch is identical with that of notch A when looking down. The isolines as a whole are less regular in their outlines than those of notch A, in addition, the area of the central striking point shrinks and its surface broke more severely by comparison with notch A. The characteristics other than those as mentioned above are fundamentally identical with those of notch A.

The dynamic traits of striking forces on notch A and B, together with the radiation of the isolines reflect that these two marks were notched by the same tool and in the same condition of motivity (behavior mode). While the deduction that the front side (the relatively wide end) is the one closer to the central striking points could be achieved through detecting the characteristics of radial isolines.

Intensity of the isolines and their wave shape. The steepness and verticality of the notch's wall can be reflected from the intensity of the isolines, the more intense, the more vertical and steeper it is. While the wave shape of the isolines indicates the extent to which the notch's wall was damaged, the less undulated, the smaller damage it suffered, and the smoother it is, which shows that the blade of the tool is relatively sharp and the extent to which the wall contacted with the tool is large. Conversely, more undulations indicate the notch's wall had undergone obvious breaches, just because of the facts that the blade of the tool had been blunt, and consequently, the extent to which the tool contacted with the processing object is low, besides, the vibration when striking is obvious. The regular direction to which the waves point reflects the focus and moving direction of the tool when striking, which could facilitate the identification of the dynamic rules of processing tools.

Notch A: The waves of the isolines center on the deepest point and expand in a radial way. The isolines at the right side of and above the deepest point are intense, and the wave is small and undulated in a small-indented manner. The isolines of the left, especially those of the below, are obviously sparse and distributing as a big wave (Figure 4). Besides, parts of blue isolines shrink significantly at the southwestern side of the deepest point to be formed into a shape of bottle neck at the bottom of the notch, which indicates that the tools should have moved down vertically from the top of the deepest point, with no horizontal slippage (forward-backward or right-left) at the bottom of the notch.

Notch B: Although the isolines of notch B as a whole are sparse and undulated too much when compared with those of notch A, its overlapping traits, distribution of wave, and so on, are identical with those of notch A.

The structures of both notch A and B can be divided into two parts, major and subordinate. The major part is that the blade of the tool contact intensely with the substantia compacta, which represents polymorphism according to the shape of the blade of tool (The part compassed by the blue isolines). While the subordinate part is that the blade of tool did not contact sufficiently with the substantia compacta, or even no contact, and that bone suffered from damage of breaking due to the indirect impacts from dynamic sources. Judged from the enclosed state of the isolines, the major parts of the two notches are identical, with both of them exhibiting the shape of cone with three sides, though the turning place between the neighboring sides is smoother in notch B than in notch A. The subordinate parts of the two notches are fundamentally identical, that is, there are all extensive ruptures at the bottom of both the notches. Besides, the turning relations are also fundamentally identical in this part of notch. On the top of the notches exhibit sunken phenomenon, this can be inspected from the non-enclosed state of the yellow isolines on the top

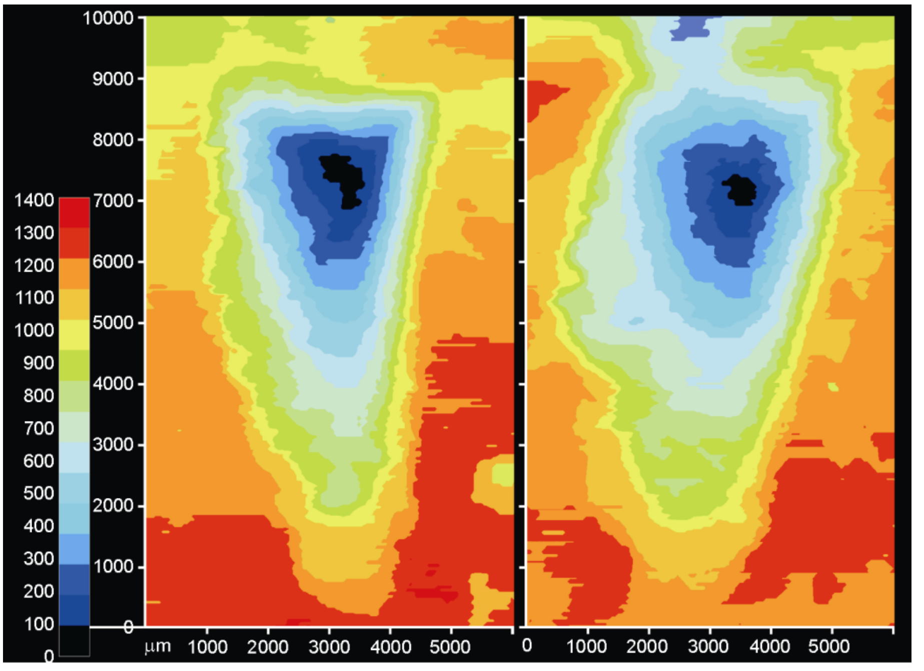

Figure 4 Isolines analysis of the orthographic projection of the notches (left: notch A; right: notch B).

of the notches. Judged from the characteristics as mentioned above, both of notch A and B come from the process of the same three-ridge tool, which stroke the bone twice in similar strength and manner of movement. Notch A should have been processed before notch B. The blade of the tool became blunt after formation of notch A.

2 Discussion and conclusion

2.1 Discovery from observing the sample excavated from site of Bailong Cave

Through the analysis of three-dimensional digital model and isolines of the direct-projection, we achieve the following conclusions about the sample TN2W2②: 59 recovered from the site of Bailong Cave.

2.1.1 Nature of notch. These two notches came from the process of hominid tool. The surface of animal fossils from human fossil site always represents various kinds of marks from the gnawing and biting of rodent and carnivore, as is shown by the samples recovered from the Huanglong Cave, Hubei Province[11]. International scholars of prehistory have mastered somewhat knowledge about the gnawing and biting marks from animals. For example, the gnawing mark from rodent is up-down symmetrical, shallow and exhibits the "U" shape. While carnivore leaves on the surfaces of bones dental print which accords well with the shape of its teeth[12]. The marks left by animals when biting and gnawing are always smooth on their surfaces of wall and bottom, with no obvious folding transition. With the help of conventional skills, scientists generally can make judgments consistent with the nature of the biting and gnawing marks left by animals, however, the conventional observations cannot draw affirm and precise conclusions about the nature of artificial notches, just because of their major dependence on plane traits. This article relies on novel methods-making three-dimensional digital model of the notch, detecting the notch model in the solid manner and from multi-perspectives, and analyzing their isolines to achieve the goals of identifying precisely the nature of the artificial marks. The notches on the surface of the sample TN2W2②: 59 excavated from Bailong Cave exhibit some typical traits as follows: there are damage and fibre faultage on the surface of the notch's wall; the turning line between the notch's wall and bottom is significant; the isolines center on the central striking point and spread in a radial manner. All of these characteristics distinctively differentiate the notches illustrated in detail in this article from those marks left by gnawing and biting of animals, which is relatively smooth, gradually deeper from on end to the other, and have no obvious turning line between their walls and bottoms.

2.1.2 The behavior mode of the primitive hominid. The marks left by primitive humans might result from various kinds of behaviors, such as hacking, striking, throwing, stabbing, notching, cutting or sawing. The behavior mode might be independent and one-off, or continuous and purposeful. The processing spots on the object, creation and type choice of the tools are all the concrete reflection of the behavior mode. After detecting the sample TN2W2②： 59, we conclude that these two notches are produced by successive movement of the same tool, the blade of which shapes like an acute triangle and is rigid. In addition, notch A formed before notch B and all of them come from stabbing of the tool. The long axial of the blade intercept the long axial of the bone, and the left notch came into being before the right one.

2.1.3 Abrasion of tools reflected in the marks. Tools used by ancient human are made of stone, bone, wood, etc. Abrasion and crash may occur when the tools are used. It is difficult to analyze the abrasion and crash of tools with traditional method of tools study. Three dimensions reconstruction and isoline analysis in this paper reveals that tools experienced evident wear whenever used, which is the base of study of tools' making and usage according to the abrasion of tools suggested in marks on the surface of bones.

2.2 The prosperity of virtual three dimensions reconstruction and isoline analysis in the study of marks in archaeological sites

2.2.1 Tools distinguishing according to the marks. Some studies about marks have been conducted[13,14]. The behavior patterns and tools usage of ancient human are of great complication, and there are differences in the style of stone tools among different areas, which is called culture differences. In this paper, we find that some marks are probably carved by three-edged sharp tools (three-edged point), which has never been proposed before. This paper is just a preliminary study to distinguish the tools according to the marks on the surface of animal fossils. We believe that this method will give us more information about human behavior and stone culture.

2.2.2 The role of virtual three dimensions reconstruction and isoline analysis on the study of marks. Virtual three dimensions reconstruction has been successfully applied in some archaeological research in China, such as phytolith and jade article[15,16]. This method is first applied to the marks study in this paper, and isoline analysis is also carried out. Studies related show that virtual three-dimension reconstruction technology has great advantage in three-dimension imaging and micro-observation. This method can give us a lot of information about marks as follows: the formation of the marks, the tools that produced the marks, the cutting edge, movement and micro-abrasion of tools. At the same time, the three dimensions technology is now under development with certain weakness. It fails to collect effective data of the inner surface features of appliance, like the inner concave stripes[16]. How to use three-dimension technology to distinguish marks caused by animal biting from that by tools still needs further analyses. Three-dimension technology is of great potential advantage in studying the relationship between marks and the tools that made them, and quite important as a way to study the behavior patterns of ancients human from marks.

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