X-rays for Archaeology

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Cover shows an image of the tomb of Amenhotep III in Egypt.
Photo courtesy of Masayuki Uda.

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Foreword

The First International Symposium on X-ray Archaeometry took place in the conference hall of Waseda University, Tokyo, Japan, on 18–20 July 2002. The participants of the symposium were from Belgium, China, France, Greece, Hungary, Israel, Italy, Japan, Korea, Mexico, Romania, Slovenia, Sri Lanka, Taipei, UK, and USA.

One of the most important aims of the symposium was to combine two scientific fields, i.e. archaeology or art and X-ray science. Finding archaeological sites, dating, analyzing of archaeological objects, and so on needs the help of natural scientists and technicians. Natural scientists have a taste for solving mysteries hidden in archaeology. However, previously, using x-ray techniques was only a small part of the archaeological fieldwork and the x-ray field was largely disinterested in the analysis of archaeological objects. Until this symposium, no attempt has been made on having an international meeting on a worldwide scale to discuss archaeological subjects under equal partnership between the two fields mentioned above.

The symposium provided a broad forum for discussing experimental results of X-ray-based analysis. Of particular interest for the participants of the symposium was the non-destructive analysis of archaeological monuments using several kinds of X-ray techniques, especially under *in situ* and contact-free conditions, as well as the introduction of experimental results using advanced technologies such as ion beam and synchrotron radiation techniques.

This book, named "X-rays for Archaeology", consists of papers selected from presentations in the First International Symposium on X-ray Archaeometry.

Finally, it is an especially great pleasure for me to warmly recommend this book to every reader interested in knowing more about X-ray archaeometry and understanding the importance of joining both scientists in the fields of archaeology or art and X-ray analysis.

Tokyo, Japan

Professor M. Uda
Chairman
Organizing Committee of the First International Symposium on X-ray Archaeometry

Part IV: Radiography

Chapter IV-1

The Use of Medical Computed Tomography (CT) Imaging in the Study of Ceramic and Clay Archaeological Artifacts from the Ancient Near East

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Keywords: computed tomography, CT, radiographic technique, X-rays, archaeology, ceramics, clay artifacts, URIII period, envelopes, curved planes, non-destructive, ancient near east, Pottery Neolithic, Shaar Hagolan Culture, figurines, ceramic technology

Abstract

Computed Tomography Imaging (CT) is highly regarded as an efficient and relatively inexpensive medical diagnostic tool. It has not, however, come into its own in the study of clay and ceramic archaeological artifacts. Our studies demonstrate, however, that Medical CT is, in fact, a singularly powerful and efficient tool for in-depth radiological studies and analysis of a wide, range of archaeological finds. As the images obtained by the CT scans are digital, we have been able to manipulate them in many ways, thereby revealing new dimensions to non-destructive X-radiological studies of archaeological finds. By adapting various image post-processing techniques, developed for the CT as a medical diagnostic tool to our specific needs, we have been able to reduce research and development costs.

1. Introduction

In this paper we present the results of imaging studies we have conducted in Israel of clay and ceramic archaeological artifacts using Medical X-Ray Computed Tomography (CT).

Medical X-Ray Computed Tomography, commonly known in the medical profession as "CT", is a non-destructive radiographic technique. It is widely used by physicians as a diagnostic tool, as it is superior in many aspects to the imaging produced in a conventional radiograph.

M. Uda et al. (eds.), X-rays for Archaeology, 231–245.

We will describe the techniques we used and demonstrate how we adapted them for use on clay and ceramic archaeological material. Emphasis will be placed on the advantages that these techniques have over other radiological imaging techniques currently in use by archaeologists.

From a wide variety of studies that we have successfully completed, we chose two examples for this paper:

A. We present the results from our testing of UR III period tablets that had been sealed in clay envelopes. We will demonstrate how we used CT imaging, a totally non-destructive research tool, to view and actually read the inscriptions on the inner tablet without tampering with the outer envelope. Furthermore, we will show that the data we collected from these scans allowed us to understand the actual techniques used by the ancient scribes in forming these envelopes.

B. We also present results from our scanning of a figurine from the Pottery Neolithic period (sixth millennium BC) at the Shaar Hagolan site in the Jordan Valley of Israel. This site has revealed the earliest finds and largest collections of figurines formed from clay material in this region of the world. We will show how these scans revealed to us the ceramic technology the craftsmen used in its production.

2. Background

Computed Tomography (CT) is a popular non-destructive radiological technique. It was developed for, and is primarily used as a diagnostic tool in the field of medicine. CT scanners can be found in every modern medical facility in the world. More recently, however, CT was found to be an indispensable tool in other areas, e.g. industry, where complex pieces of machinery and even pipes are scanned.

Computed Tomography (CT) is proving to be a very practical diagnostic tool for archaeological studies:

1. The testing process is fast and non-destructive.
2. The data collected is digital and can be stored for future post-scanning processing.
3. The stored digital images can be printed, in fine detail, on film or paper.
4. A wide variety of post-scanning computer applications have been developed for the medical radiological community. We have succeeded in adapting some of these applications for use in our studies of archaeological material. Not having to develop new computer applications has drastically cut research costs.
5. The availability of CTs in almost every modern community makes it an ideal tool for archaeologists and conservationists. Research projects are invariably delayed by bureaucratic red tape when the shipping of artifacts to distant laboratories for testing requires official permission.

Some archaeologist and museum conservationists have already recognized the potential of CT. Projects have been published demonstrating the use of CT in the study of human and animal bone material (Anderson 1995, Davis 1997), Mummies

(Notman 1986; Pahl 1986) and plastered skulls (Hershkovitz et, al. 1995).

Industrial and high energy CT has been shown to be of great potential in the study of metal artifacts (Mazansky 1993; Bossi 1990).

The successful use of CT as an efficient and very powerful non-destructive analytical tool for the study of clay and ceramic archaeological artifacts is reported in our numerous papers and monographs (Applbaum et al. 1994; 1995; 1998; 1999; 2001; 2003; Jansen et. al. 2001). Aside from our work, only a limited amount of other projects have been conducted and published to date. Furthermore, not always have sufficient results been obtained (Lang and Middleton 1997; Carr 1990; Vandiver et. al. 1991).

3. The Technique

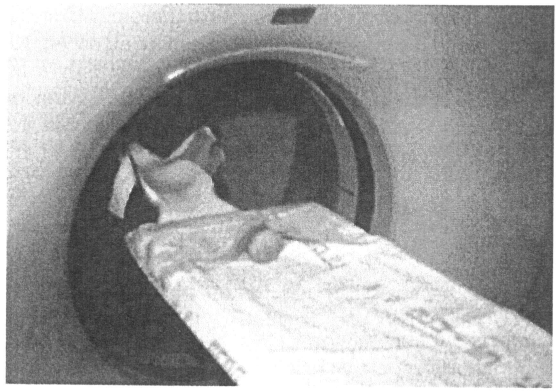
In CT, "*Figure 1*", an X-Ray tube and a series of electronic detectors rotate around an object. The X-rays pass tangentially through the scanned object and are measured by detectors. A digital image is formed from the collected data. Consecutive "slices" through the object form a series of images that provide a full picture of the object in cross section. The advantage of CT is that the overlapping parts of the object do not obscure the image under study, as they do in standard X-rays. Furthermore, because the data is acquired as a volumetric data set, it can be manipulated, not only to form images in different planes but also to generate 3-D images.

The scanning process is performed in two stages; followed by post-scanning processing and interpretation of the data collected.

First, a preliminary scan called a "surview" or "scout scan" is preformed. In this scan a digital radiograph of the object is taken. This image is a 2 dimensional representation of a 3 dimensional object; similar to that which is obtained by conventional radiography. The contrast and clarity of these digital radiographs, however, are of much higher quality than of those obtained with conventional radiography. These preliminary images have, time and again, proven to be invaluable in our study of these artifacts.

The "surview" helps us in planning the CT study. Our first step is to mark, on the surview, the exact area or areas we want to scan. Only then do we decide upon the exact distance between, and the thickness of the slices. Furthermore, based upon our preliminary observations of these 2 dimensional radiographs, we can, if needed, concentrate or focus our "second stage" scanning on specific areas.

The object is then passed through the scanner with "slices" being produced, as predetermined by our study of the surview. In this particular study we scanned thin slices using a high-resolution technique to attain fine detail and good contrast. Our CT scanning process allows us to observe both qualitative and quantitative differences in the densities of the material from which the scanned artifact was made.



"Figure IV-1-1", Medical Computed Tomography of an archaeological artifact.

To achieve even finer detail of the artifacts under study, we found that, by using an "edge enhancing" algorithm or filter and viewing the artifacts with a wide graphic "window", we were able to achieve superior results.

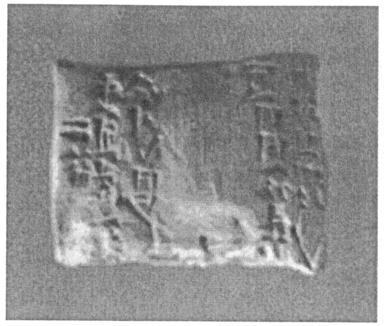
In the post-scanning stage we viewed the images of the scanned slices on an on a Proview (Algotec, Raanana, Israel) high-resolution screen. We also selected images of scanned slices for printing on film.

Software applications as such allow us to further broaden our understanding of the artifact, in the "post-scanning" stages of our study. They make it possible to examine and analyze the images, obtained during the scanning phase, in depth and with great accuracy. Among the most useful applications we use, are the various filters that facilitate to enhance the scanned images. These filters allow us to "soften" or "harden" the contrast of the images. This often helps us to view voids and inclusions in the mass of the clay or ceramic material that we might have otherwise overlooked.

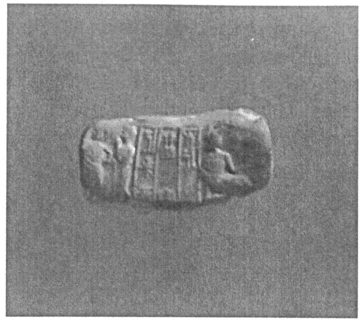
Graphic tools are used to quantitatively measure different features of the image, such as the length, width or thickness of specific features. We can also measure the comparative density at various points of the material. These comparative studies, helps us determine possible connections between different artifacts as well as to compare variations in quality.

4. Envelopes *"Figures 2, 3"*

At various archaeological excavations, in Mesopotamia and Turkey, 1000's of sealed "Envelopes" have been discovered. These envelopes are clay or ceramic containers within which cuneiform tablets were inserted and sealed for safe keeping.



"Figure IV-1-2", Envelope - note cuneiform inscription and seal.



"Figure IV-1-3", Envelope – note seal on side of envelope.

The tablets that we have been working on are, strange to say, economic documents in the Sumerian language. To be exact, they are legal receipts from the Ur III period dated to the 21st century BCE. The kings of this dynasty, whose capital is traditionally identified as the Ur of the Chaldees mentioned in the first book of the Bible, Genesis, developed a royal nationwide bureaucracy. Our knowledge of that dynasty is based, in the main, on information gained from the study of these clay tablets are literally. There are thousands, if not more of these Ur III documents in existence. They are found in public and private collections all over the world.

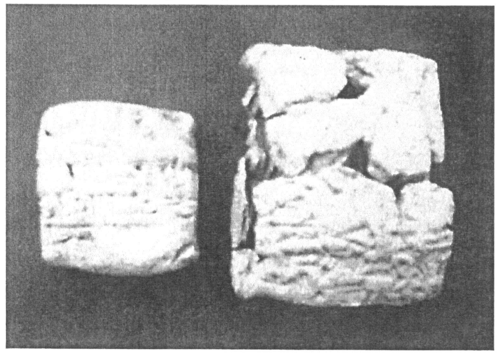
The envelopes we have studied are from the collection of the Institute of Archaeology at the Hebrew University of Jerusalem. A private donor with no information available as to its provenance donated them to the collection.

In antiquity, in the URIII period, it was common practice among scribes to inscribe documents on clay tablets using the cuneiform writing system. Most of these tablets were legal documents. To guarantee the authenticity of the document and discourage possible tampering and/or forgery of the said document, the scribe sealed it in a clay container, thus the name "Envelope" (Chiera 1938:69-74).

Upon sealing the tablet in the envelope, the scribe would write a summary of the text on the envelope (Hallo and Weisberg 1992: 52). Often, the exterior of the envelope bore the seals of witnesses (using cylinder seals) as well as the identity of its owner. Some of these seals contain glyptic designs. The seals themselves are of unique artistic value (Leinwand 1992).

The seals and text on the envelope served as a security system to protect the inner tablet from being tampered with, after it was sealed in its envelope (Collon 1987: 113-114). If the matter was later contested, the envelope was produced in court; the witnesses would be called upon to identify their personal seals, and then the envelope would be broken open. This ancient security system had proven to be fool-proof.

The current state of the art in reading Ur III envelope texts is to copy or photograph the text and seals on the exterior of the envelope. The envelope is then breached so as to "get at" the text inside. Thus, the study of these documents presupposed the physical destruction of the envelope, an important part of the artifact. This destruction is irreversible. The clay envelope, the seals and texts are invariably damaged in the process of opening them *"Figure 4"*.



"Figure IV-1-4", Envelope after being opened – note irreversible damage.

The aim of our research was to seek a non-destructive technique that would allow us to read the inner tablet without damaging the exterior envelope.

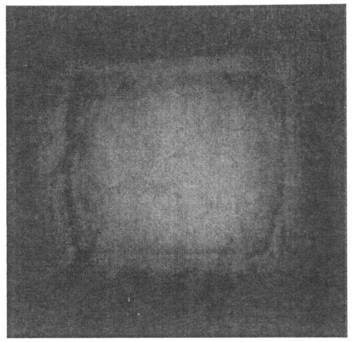
It was obvious from the very beginning that conventional radiology would not be of much use to us. Nevertheless, we tried conventional X-rays. The X-rays revealed, only, that there was a tablet concealed inside the clay envelope *"Figure 5"*.

They did not, and could not reveal that the tablet was inscribed. Our findings reflect the major limitation of conventional X-rays where all structures through which the rays pass are superimposed on the image produced, making it difficult, if not impossible, to distinguish particular features

We also experimented unsuccessfully with conventional tomography. Conventional tomography is a technique by which the shadows of superimposed structures of an X-ray can be "blurred", thereby highlighting the structure to be diagnosed. This allows the diagnostician to see more clearly the structure with which he is presently concerned. The sharpness of the image, however, cannot be enhanced. Conventional tomography, therefore, could not offer us a clear view of the text inscribed on the tablet inside the sealed envelope.

Medical Computed Tomography was found to be the best, and perhaps the only tool available, as of now, that affords us the opportunity of being able to read the text inscribed on the tablet while sealed inside the clay envelope. Whereas, all previous imaging modalities in Medicine, such as Radiography, are simple geometric projections of the object onto detectors (film), computed Tomography produces results vastly superior to that of other systems. To begin with, its X-rays pass through the subject at different angles, eliminating superimposition and enabling individual structures to be viewed in insulation. CT also detects subtle differences in the density of the structures observed and presents them on the computer screen in

graduated shades from white, for dense substances such as bone or metal, through a succession of grays to black. Furthermore, CT uses multiple planar projections. These planar projections are mathematically recombined by a digital computer to provide a cross sectional image of the object.



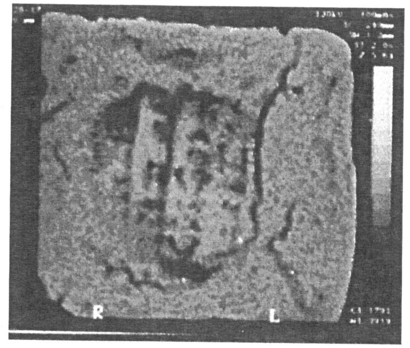
"Figure IV-1-5", Conventional X-ray radiograph of envelope.

In this study we used a high resolution 3rd generation CT scanner - an Elscint 2400 elite scanner. The envelope was placed with its flat side parallel to the scan plane. The scanner examined the envelope in a series of lateral overlapping "slices".

The object was scanned with an image matrix of 512 x 512 with thin, 1.2 mm slices.

An algorithm, developed for the diagnosis of fine bone detail, was used to reconstruct the raw data. To maximize our imaging parameters, to get the best possible image, we sacrificed contrast, radiation dose and signal to noise ratio. This gave us higher resolution and sharper edges. Because the clay of the tablet is dense and air fills the voids created by the impressions, which are the cuneiform text inscribed on the inner tablet, we were able to achieve the highest possible contrast "Figure 6".

In the scans of the lateral sections, clear high contrast images of most of the inner tablet's face were obtained. It is possible to see and even read most of the cuneiform text. One of the problems we faced while testing the envelope, however, was when we found that the writing surface of the tablet sealed inside the envelope was convex. This resulted in many of the cuneiform signs on the surface of the inner tablet being "cut" by the "slicing" of the scanner. We were only able to view limited sections of the text, inscribed on the surface of the convex inner tablet, in each section obtained in the scanning process.



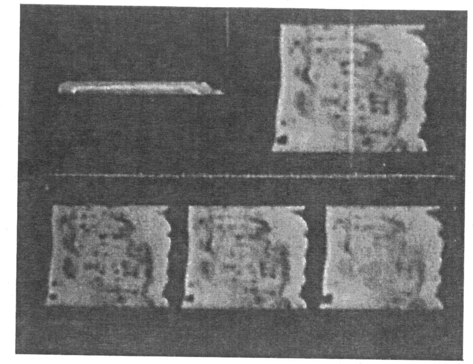
"Figure IV-1-6", CT section of envelope – note lines of cuneiform writing

In order to obtain an imaging of the whole face of the inner tablet with all the Cuneiform signs visible, we utilized post-scanning data processing. Using all the digital data collected and stored during the scanning stage we were able, with the aid of a variety of computer software programs, to reconstruct or reformat the surface of the inner tablet. To be able to image the full text from the reformatted surface, we used an imaging process technique known as "curved planes" multiplanar reformatting (Newton and Potts 1981).

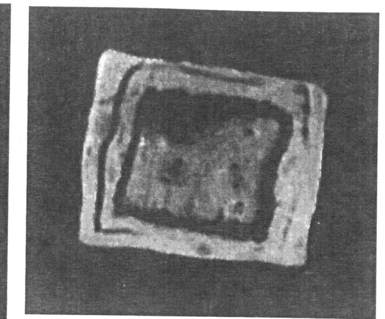
The successful reformatting of curved planes assumes that the lateral scanned slices of the tablet are properly stacked one on top of the other, with minimal movement or change in other imaging parameters. It is then possible to select voxels in planes other than the ones in which they were originally obtained. This technique allows us o obtain images in orthogonal planes or non-orthogonal (oblique) or even curved planes. It is then possible to select voxels in planes other than the ones in which they were originally obtained. This technique makes it possible to obtain images in orthogonal planes or non-orthogonal (oblique) or even curved planes. In general, using curved planes requires a great deal of meticulous planning and great deal of time-consuming effort as the contour of the object must be carefully traced on multiple levels in order to be able to bring out as much of the information as possible. This is especially true with some of the tablets whose surface appears to be uneven.

We are of the opinion that, as far as our scanning procedures are concerned, we have attained more than adequate results. The fact is that we are now able, by reformatting in curved planes, to decipher the inscription on the inner tablet's surface without affecting the outer envelope in any way, whatsoever. "Figure 7".

In addition to the imaging of the inner text, we found that CT also supplies us with valuable information as to the technology used by the ancient scribes in forming these envelopes (Collon 1987:114).



"Figure IV-1-7", Envelope - "curved planes" multiplanar reformatting.

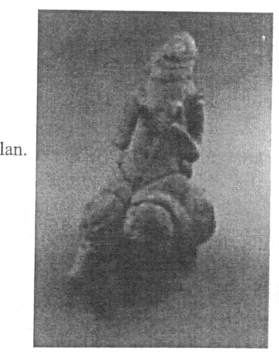


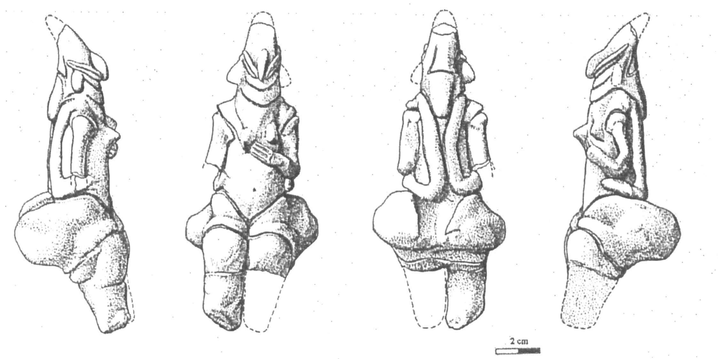
"Figure IV-1-8", CT section of envelope – note the layers formed while sealing the envelope.

We are able to view and measure the thickness or thinness of the envelope in each of the sections. We have determined that in some cases the scribe wrapped the inner tablet in two layers of clay that formed the envelope "Figure 8". The corners were pinched, pressed and squared off. All signs from the forming process of the envelope were then smoothed over and concealed by the scribe. The final product was a square shaped tablet with a smooth exterior, upon which the scribe could write the summary of the internal document and upon which the witnesses could stamp their seals. In the future we plan to publish, with the help of Dr. Wyane Horowitz of the Hebrew University of Jerusalem Israel, the full decipherment of the cuneiform texts from the envelopes we studied.

5. Anthropomorphic Figurine, from the Pottery Neolithic Period Site of Shaar Hagolan *"Figures 9, 10"*.

"Figure IV-1-9", Anthropomorphic figurine from Shaar Hagolan.





"Figure IV-1-10", Anthropomorphic figurine from Shaar Hagolan – technical drawing.

The site of Shaar Hagolan , in the northern Jordan Valley in Israel, is where the Pottery Neolithic Yarmukian culture had been first identified (Stekelis 1951, 1972; Garfinkel 1993; Kafafi 1993). The largest assemblage of prehistoric art ever excavated in Israel has been uncovered at this site. Previous studies of similar Yarmukian anthropomorphic figurines had concluded that a standard core technique was employed in their forming (Garfinkel 1995:30-31; Mozel 1975; Yeivin and Mozel 1977:196). This conclusion was based solely on external examination of fragments from figurines previously excavated at this site and other Pottery Neolithic Yarmukian culture sites.

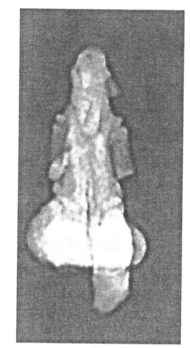
The Pottery Neolithic period in this region marks the beginning of all ceramic technology. Their use of only one, standard forming technique in this genesis period is to be expected. After all, as the people of this culture pioneered ceramic technology, we may assume that, at such an early stage of development, they had not yet achieved technological variability. On the other hand, one might expect to find at least some experimentation being conducted by these Shaar Hagolan people, even at their earliest learning stages of the new technology. Such experiments would have led to technological variability with a possible preference of one technique over the other.

In an earlier study we conducted, we used medical computed tomography to help in the conservation and restoration of two parts of a statue, from the site of Shaar Hagolan (Applbaum et al. 1998). There we found clear evidence that the core technique was used "Figure 11". But other figurines from this site that we tested at the time, for conservation and restoration purposes, showed possible signs of other ceramic techniques having been used. Based on this premise we decided to broaden the scope of our post-scanning analyses to include an in-depth study of the ceramic technological abilities of the people of the Shaar Hagolan culture.

"Figure IV-1-11", CT section along the longitudinal axis – note the use of the core technique.

To further our thesis we present our scanning of a figurine (63X35X21 mm.) that was excavated at the Pottery Neolithic site of Shaar Hagolan during the 1997 season (Garfinkel 1999: 48). It is an almost complete anthropomorphic figurine, having only slight damage to the legs. It is a fine example of the technological and artistic abilities of the craftsman of the Yarmukiam culture.

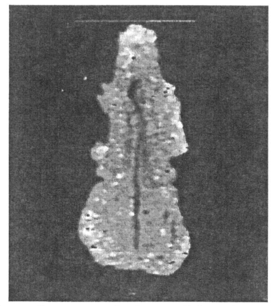
The study of this object was conducted on a third generation CT scanner. The scanning techniques we used have been explained in our study of the "envelope", above. In this study we first conducted a "scout view" or surview, a two dimensional digital radiograph of the object "Figure 12". As mentioned above, the CT technicians



"Figure IV-1-12", Surview (scout view) of figurine

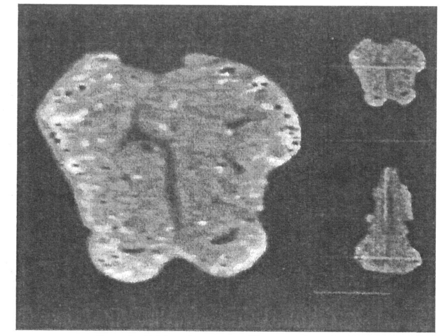
use this image in the planning of the sectional scanning that follows. We may note that in most cases the surview is not very helpful to us because it has limitations similar to those of conventional radiography, namely, two-dimensional projections of three-dimensional objects, causing a superimposition of impenetrable layers. This often leads to a misinterpretation of the surview image. In our study, however, the surview proved very helpful in determining that this figurine has a complex internal structure. The exact nature of this complexity could not be fully determined based on the surview alone. Using both the surview and the second-stage CT scanning, however, we were able to determine the exact technique used in the forming of this particular artifact. We conducted a full set of CT sections, scanning along the longitudinal sagittal plane of the figurine. We could find no sign of the core technique, discussed above, having been used in the modeling of this figurine. In our previous testing of figurines we had found that the core technique could be easily identified in CT scans. Air voids are captured between the core and the material modeled upon the core. This difference in density (air / clay) is clearly viewed in the results of CT scanning. In our current study, however, no core could be identified. Our density studies showed voids of air that were captured in areas where pieces of clay were added to the exterior of the figurine in the final phase of its production.

We also observed an abnormality in a CT section passing through the center of the figurine along its coronal plane "Figure 13". In order to better understand the nature of this abnormality, we decided that an axial sectional view of this area of the figurine was called for.



"Figure IV-1-13", CT section along the coronal plane of figurine – note abnormal "fuzziness" along center of image

Having conducted a full scanning series of overlapping thin slices along the longitudinal plane, we already possessed a full data set. We processed this data on an Omnipro Workstation. With using multiplanar reformatting, we were able to reconstruct a view of the axial plane section for any area of the object, without having to rescan the figurine. In the reconstructed axial section we were able to determine that there was a void that caused fuzziness along the coronal plane of the figurine "Figure 14". This void and the low density lines we observed in the axial section were caused by air trapped between the folds of clay at the time when the clay slab was folded and pasted.



"Figure IV-1-14", Using multiplanar reformatting – reconstruction of the axial plane section.

The exact nature of this void, that caused the fuzziness, could not be understood until it was viewed in the adjoining axial section. In the axial section the void clearly defines the modeling technique used to form this figurine from the Neolithic period. Instead of forming the figurine on a core, the craftsman formed the body of the figurine from a single slab of clay. The slab was folded in half along its longitudinal axis, to form the main body of the figurine. The fold is, therefore, contained inside the mass of the body of the figurine. Buttocks and eyes and other refinements were then pasted on the body. All signs of the voids caused by the folding of the slab of clay that forms the body of the figurine and all refinements that were pasted on the body were then smoothed over and concealed by the craftsman. They cannot be observed in any way by an external viewing of the object. We were only able to identify the techniques used in the forming of this figurine after an exacting study of the voids that were revealed to us by our CT reformatted sectional images.

6. Conclusions

We have demonstrated, as shown in this paper, that standard medical Computed Tomography (CT) can be a very practical and powerful diagnostic tool for the study of ceramic and clay archaeological artifacts. The use of this non-destructive diagnostic tool in research, offers the archaeologist the opportunity to:

1. "See" inside artifacts without damaging them.
2. Determine what techniques were used in the production of ceramic and clay artifacts.
3. Conduct conservation of the most delicate artifacts with great confidence, making use of density scans that determine the parameters of the object.

This, however, tells only half the story. Cost and convenience considerations make the medical CT even more ideal for archaeological research of clay and ceramic artifacts, because of the following:

1. CT's are available, worldwide; they can be found in Medical centers, hospitals and even in private labs. There is no true need to invest in the

purchase of this very expensive equipment. Time can usually be rented on a CT. The cost of testing is, therefore, relatively inexpensive. This drastically reduces research and development expenses.

2. There is no need to ship artifacts to distant labs for analysis. This eliminates shipping and insurance costs and a great deal of red tape.
3. Once the artifact is properly scanned and the data stored there is no further need of and convenience of the researcher.
4. The archaeologist can make use of a wide variety of computer applications that have been developed for the medical profession without incurring the expense of developing new ones.

This paper, limited to just two examples from our extensive work on ceramic and clay artifact, cannot cover the full scope of our research; nor does it explore the full potential of this system, as we now know it

This First International Symposium in Tokyo enabled us to share, with a broader scientific community, our experiences and successes in the testing of clay and ceramic artifacts using Medical CT. It is our hope, that the momentum achieved in this first meeting, will be followed by others, bringing us together time and again in the years to come.

7. References

Anderson, T. (1995) Analysis of Roman Cremation Vessels by Computerized Tomography, *Journal of Archaeological Science* **22**, 609-617.

Applbaum, N., Applbaum, Y.H., and Horowitz, W. (1994) Computed Tomography Imaging of Sealed Clay Cuneiform Tablets, *Imaging The Past - Electronic Imaging and Computer Graphics in Museums and Archaeology*, Abstracts, British Museum, p.18.

Applbaum N., Applbaum, Y.H., and Horowitz, W (1995) Imaging with the Aid of Computed Tomography of Sealed Documents from the Ur III Period, *Archaeology and Science Bulletin* **3**, 8-12. (Hebrew)

Applbaum N., Applbaum, Y., Lavi M., and Garfinkel, Y. (1998) Computed Tomography Imaging as an aid in the Preservation and Conservation of Neolithic Figurines from the Site of Sha'ar Hagolan, *Archaeology and Science Bulletin* **6**, 46-54 (Hebrew).

Applbaum, N. and Applbaum, Y. (1999) The Use of Medical Computed Tomography (CT) in the Study of Ceramic Archaeological Finds, in N. Messika, N. Lalkin and J. Breman (eds.), *Computer Applications in Archaeology*, Conference Proceedings, Tel Aviv, pp. 42-52 (Hebrew)

Applbaum, N., and Applbaum, Y.H. (In preparation) Medical Computed Tomography (CT) of Selected Pottery: Preliminary Results, in A.M. Maeir (ed.), *Bronze and Iron Age Tombs at Tel Gezer, Israel: Finds from the Excavations by Raymond-Charles Weill in 1914 and 1921.*

Bossi, R.H., (1990) Computer Tomography of Ancient Chinese Urns, *Materials Evaluation* **48**, 599-602.

Carr, C., (1990) Advances in Ceramic Radiology and Analysis: Applications and Potential, *Journal of Archaeological Science* **17**,13-34.

Chiera, E., (1938) *They Wrote on Clay*, Chicago ILL, University of Chicago Press.
Collon, D., (1987) *First Impression Cylinder Seal in the Ancient Near East,* London, British Museum Publication.

Davis, R., (1997) Clinical Radiography and Archaeo-human Remains, in J. Lang and A.Middleton (eds.), *Radiography of Cultural Material*, Oxford, Butterworth-Heinemann, pp. 117-135.
Garfinkel, Y., (1993) The Yarmukian Culture in Israel, *Paleorient* **19:1**, 115-134.

Garfinkel, Y., (1995) *Figurines and other Baked Clay Objects from Munhata*, (Les cahiers du centre de recherche francais de Jerusalem 8), Association Paléorient, Paris, Direction General des Relations Cultrelles Scientifique et Techniques du Ministere des Affaires Etranger.

Garfinkel, Y., (1999) *The Yarmukians - Neolithic Art from Sha'ar Hagolan*, Bible Lands Museum, Jerusalem.

Hallo, W.N., and Weisberg, D.B. (1992) A Guided Tour through Babylonian History: Cuneiform Inscriptions in the Cincinnati Museum, *The Journal of the Ancient Near Eastern Society* **21,** 49-90.

Hershkovitz, I., et. al. (1995) Remedy for an 8500 Year-old Plastered Human Skull from Kfar Hahoresh, Israel, *Journal of Archaeological Science* **22**, 799-788.

Jansen, R.J., Koens, H.F.W., Neeft, C.W., and Stoker, J. (2001) Scenes from the Past: CT in the Archaeologic Study of Ancient Greek Ceramics, *RadioGraphics* **21**, 315-321.
Kafafi, Z., (1993) The Yarmoukians in Jordan, *Paleorient* **19**, 101-114.

Lang, J., and Middleton, A. (1997) Radiography - Theory and Practice, in J.Lang and A.Middleton (eds.), *Radiography of Cultural Material*, Oxford, Butterworth-Heinemann, pp. 117-135.

Leinwand, N. (1992) Regional Characteristics in Styles and Iconography of the Seal Impressions of Level II at Kultepe, *The Journal of the Ancient Near Eastern Society* **21,** 141-172.

Mazansky, C. (1993) CT in the Study of Antiquities: Analysis of a basket-hilted Sword Relic from a 400-year-old Shipwreck, *Radiology* **186**, 55A-61A.

Mozel, E. (1975) A Special Human Figurine from the Pottery Neolithic in Israel, *Mitekufat Ha'even* **13,** 70-73 (Hebrew), 74 (English summary).
Newton, T.H., and Potts, D.G. (eds.) (1981) *Radiology of the skull and Brain: Technical aspects of Computed Tomography*, Vol. 5. ,CV Mosby ,St. Louis.

Notman, D.N.H. (1986) "Ancient Scanning: Computer Tomography of Ancient Mummies". in R.A. Davis (ed.), *Science in Egyptology*, Manchester University Press, Manchester, pp. 251-320.
Pahl, W.M. (1986) Possibilities, Limitations and Prospects of Computer Tomography as a Non-invasive Method of Mummy Studies, in R.A. Davis (ed.), *Science in Egyptology*, Manchester University Press, Manchester, pp. 13-24.

Stekelis, M. (1951) A New Neolithic Industry: The Yarmukian of Palestine, *Israel Exploration Journal* **1,** 1-19.

Stekelis, M. (1972) *The Yarmukian Culture of the Neolithic Period*, Magnes Press, Jerusalem.

Vandiver, P. et. al. (1991) New Applications of X-Radiographic Imaging Technologies for Archaeological Ceramics, *Archeomaterials* **5**, 185-207.

Yeivin, E., and Mozel, I. (1977) A Fossil Directeur Figurine of the Pottery Neolithic A, *Tel Aviv* **4**, 194-200