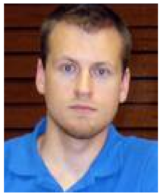
The Linothorax Project

Gregory S. Aldrete with Scott Bartell and Alicia Aldrete



This project took on the challenge to uncover how the mysterious "linothorax" armor of Alexander the Great was constructed from linen and glue.

I am a professor at the University of Wisconsin-Green Bay who teaches ancient Greek and Roman history. About a decade ago, one of my students, Scott Bartell, decided, as a summer project, to make himself a replica of the mysterious armor that Alexander the Great is shown wearing in a famous mosaic from the city of Pompeii. Known as a *linothorax*, this type of armor was apparently made out of just linen. Little did I realize that much of the next eight years would be dominated by the quest to understand and reconstruct that armor, as we attempted to make and test replicas of it, using only methods and materials that would have been employed in the ancient world.

When Scott asked me for advice about his project, I confidently assumed that I could just look up a few scholarly articles on the armor and give them to him, but to my surprise, I discovered that there was no definitive agreement on what the armor was made of, or how it was constructed. Thus was born the University of Wisconsin-Green Bay *Linothorax Project*, which would grow into a multi-year investigation, using the methods of experimental archaeology. It eventually involved a number of university professors and dozens of students, as well as community members, ranging from traditional weavers to bowhunters. It also resulted in a book documenting our findings: *Reconstructing Ancient Linen Body Armor: Unraveling the Linothorax Mystery*, published by The Johns Hopkins University Press in 2013.

Gregory Aldrete wearing linothorax reconstruction made from layers of laminated linen.

According to ancient literary sources, the linothorax was a popular form of armor for many different cultures, but it had been afforded little attention by scholars because, due to the highly perishable materials of which it was constructed, no specimens have survived. This contrasts with the many fine specimens of ancient metal armor that can still be seen in museums around the world. In addition, the linothorax may have been somewhat neglected because many modern commentators have been skeptical that any armor made primarily out of fabric could have offered credible protection.

To tackle this mystery, the first thing we had to do was find out as much information as possible. We had two main types of sources to work with: ancient authors who mention either the linothorax or linen armor in general, and depictions of it in ancient art.

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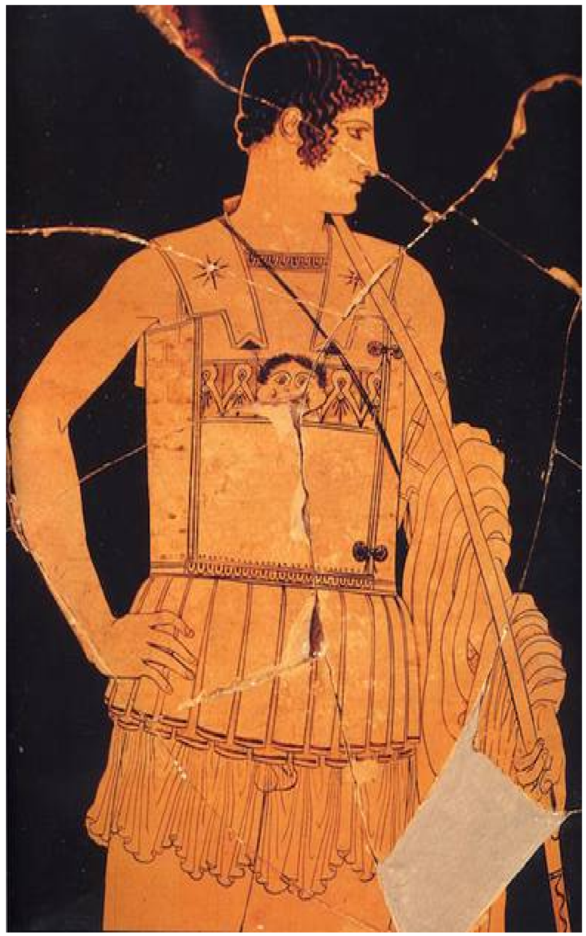
One misconception that often comes up in discussions of this armor is that the word "linothorax" (or "linothorex") is either an invented modern term, or was very rarely used by ancient authors. Neither is true. In Greek, "thorax" can mean "chest" or "abdomen," but this word is also the standard term for any sort of body armor, most typically a bronze cuirass. A linothorax literally means some sort of body armor made of linen.

The term "linothorax" shows up early in Greek literature, appearing twice in the famous ship list in Homer's *Iliad* (2.529, 2.830). In all, we located 41 usages by 27 authors. This may not sound like much by modern standards, but for an ancient Greek word, it represents a very solid body of evidence, and it is far more than we have for innumerable words that are universally accepted as legitimate ancient terms.

There are also a set of ancient citations that explicitly describe body armor made of linen, most commonly using some variant of the phrase "thorax linou" or "a thorax of linen." Collectively, there are at least 65 distinct textual references to linen body armor by more than 40 different ancient authors. Among the civilizations that we know wore it are the Egyptians, Assyrians, Nubians, Persians, Phoenicians, Romans, Carthaginians, Greeks, Macedonians, Samnites, Lusitanians, and Chalybes.

Next, we had to find all the examples in ancient art that might possibly depict this type of armor. These include vase paintings, reliefs, sculptures, mosaics, and tomb paintings. My wife, Alicia, who did much of the work assembling the database of images, spent countless hours in libraries examining every page of the hundreds of oversized volumes of the *Corpus Vasorum Antiquorum*, which catalogues the Greek vases in museums around the world. Every time we visited a museum, we kept our eyes peeled for possible *linothorakes*; and while



Ancient Greek vase painting showing the legendary hero Achilles wearing a linothorax.

one expects to find plenty represented in the museums of Greece and Italy, we were pleased to find them in such unexpected places as Kansas City and Odessa (in the Ukraine) as well. Suddenly, as so often happens during research, the linothorax seemed to be everywhere.

The images that we focused on depict soldiers, both Greeks and foreigners, wearing a distinctive type of armor that appears to be made out of two main sections—a long, rectangular piece that wraps around the body, forming a tube or cylinder, whose two ends are then fastened together with ties, usually on the left side; and a piece that fits over the shoulders, with two arm-like projections called *epomides* that come down on either side of the head and are then tied down on the wearer's chest.

Since some vases clearly show warriors in the process of arming themselves bending the rectangular body section from a flat shape to a tubular one, and since the shoulder piece is similarly bent from a flat shape to a curved one, it is plain that these corselets cannot be made of metal, but instead must be made out of some flexible material. On the other hand, the epomides are regularly portrayed as standing rigidly upright before they are bent down and secured, so the material in question must also be fairly stiff.

This combination of flexibility and rigidity is an unusual one. It has long been suggested that a solution for what this mysterious material may have been can be

Bending *epomides* into curve over sholders: recreation (left) and drawing from an ancient vase painting (right). Note squared ends on recreation, common in period before Persian War. Drawing has rounded ends, dominant after this time.

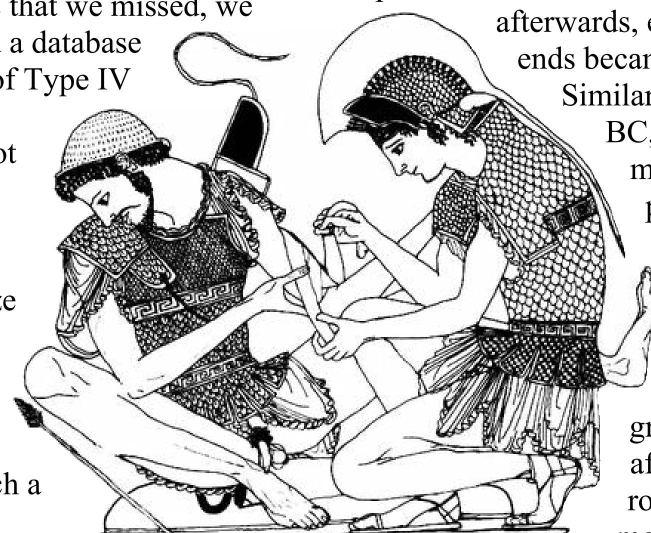
found by identifying these images with the linothorax mentioned by ancient authors. We believe that many, perhaps most, of these images do indeed portray linothorakes; however, they could also depict armor made out of other materials, such as leather. It would be wrong to label all such images as warriors wearing a linothorax.

Particularly among re-enactors, it has become standard to refer to this type of armor shown in ancient art by the descriptive term "tube-and-yoke" corselet – a phrase that recalls the distinctive shapes of the two main components of the armor. For whatever reason, this terminology has not caught on in scholarly circles, but in his 1995 book, *Archaiologia on Archaic Greek Body Armor*, Eero Jarva proposed a complete typology of armors in which this sort of design is labeled "Type IV" armor. While there is no doubt that "tube-and-yoke" is more visually descriptive, Jarva's term has the advantage of placing the armor within a broader chronological, typological, and developmental context. For these reasons, it is the one that we have chosen to employ.

For the first time, we systematically attempted to collect all extant images of Type IV armor in all forms of art. While there are no doubt examples that we missed, we have assembled a database of 913 images of Type IV armor on 486 different items. These include not only 572 images on vases, but 115 in stone sculptures or reliefs, 41 in terracotta, 158 bronze or gold statues or engravings on bronze objects, and 27 paintings on tombs or sarcophagi. Having such a large body of visual material to work with allows types of quantitative analysis that were not previously possible.

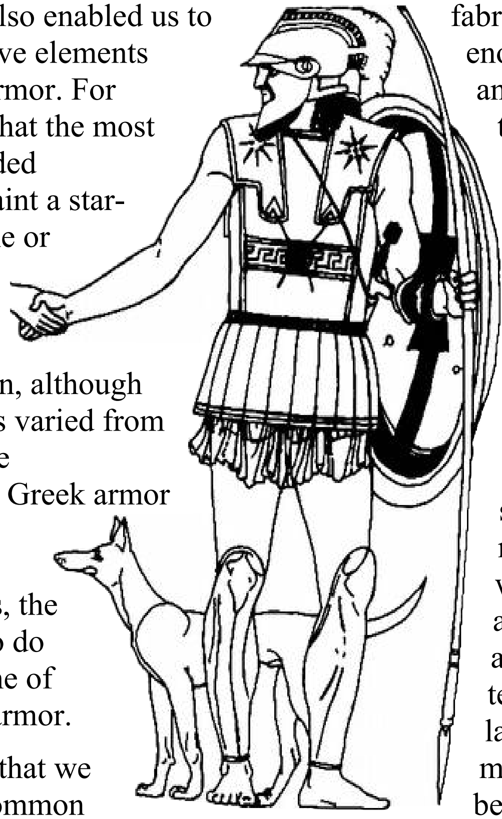
For example, some images of Type IV corselets show that the protective quality of the armor had been enhanced by adding panels of scales, made of metal or other materials. This observation has led to scales being included in many (perhaps even most) reconstructions of Type IV Greek armor. However, analysis of the database of images reveals that such scales were relatively rare, appearing on fewer than 20% of images of Type IV corselets from the Greek world, although they feature on a significantly higher percentage of Etruscan Type IV armor.

Another interesting insight into Type IV armor that emerged from our analysis of our database was that epomides that ended in a squared-off shape were most common prior to the era of the Persian wars, but afterwards, epomides with rounded ends became dominant. Similarly, up until around 475 BC, it was typical for the main part of the armor to possess a double row of pteruges, or flaps, projecting from its bottom edge to provide some protection to the groin and thighs, but after 475 BC, a single row of pteruges became more common.



Scales appear rarely, primarily on Etruscan versions.

The database also enabled us to analyze the decorative elements found on Type IV armor. For instance, we found that the most frequent form of added decoration was to paint a star-shaped design on one or both of the epomides. An 8-pointed star was the most common design, although the number of points varied from 4 to 16. So if you are reconstructing some Greek armor and want to adorn it with historically accurate decorations, the most typical thing to do would be to paint one of these stars on your armor.


Vase painting with 8-point stars on epomides.

Some patterns that we thought would be common turned out not to be. For example, the well-known "Greek key" or meander pattern was extremely rare, only appearing about a dozen times. The entire database of images is listed in our book, and we hope it will serve as a useful analytical tool for others interested in the form and decoration of ancient armor.

Finally, we were ready to attempt to "reverse engineer" from our database of images, and try to construct our own linothorax. When discussing linen armor, a number of the literary sources mention the fabric being folded or multi-ply, and if enough layers were piled on top of one another, this technique has the potential to create sturdy armor. Many other cultures successfully employed similar armor, in which multiple layers of fabric are stitched together, sometimes with additional stuffing inserted between layers, to produce a quilted effect.

Several decades ago, historian Peter Connolly made the interesting suggestion that, rather than being sewn, the layers of the linothorax might have been laminated together with glue. Archeological evidence attests that the Greeks and other ancient peoples possessed the basic technology of laminating together layers of linen. Small sections of multi-layered laminated linen have been found among caches of weapons in graves at Mycenae and Tarquinia, and identified by their 19th century excavators as having come from linen corselets.

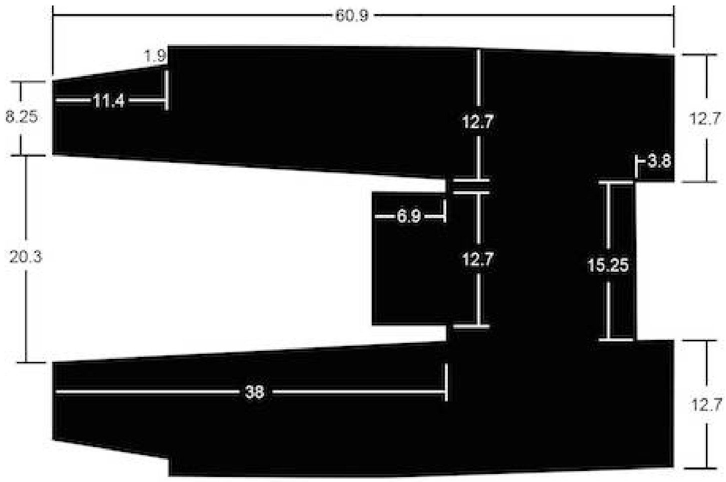
Ongoing research by Professor Amy Cohen of Randolph College reveals that the masks worn by actors in Greek plays were likely made out of laminated layers of linen, providing further evidence that the Greeks were familiar with such technology. All of this evidence was compelling enough that we decided to make some of our reconstructions from laminated layers of linen. For comparison, we also fabricated some where the layers were only stitched together.

Like fashion designers, we first made many patterns out of paper and then cardboard (next page), until we achieved our optimal design that seemed to match up accurately with the images and descriptions. Then came the tricky part. We wanted to employ only materials that would have been available in the ancient Mediterranean, so we had to get ahold of hand spun, handwoven linen. Since most linen these days is machine-made, we couldn't just go to the local fabric store. We soon discovered that even linen being sold on the internet

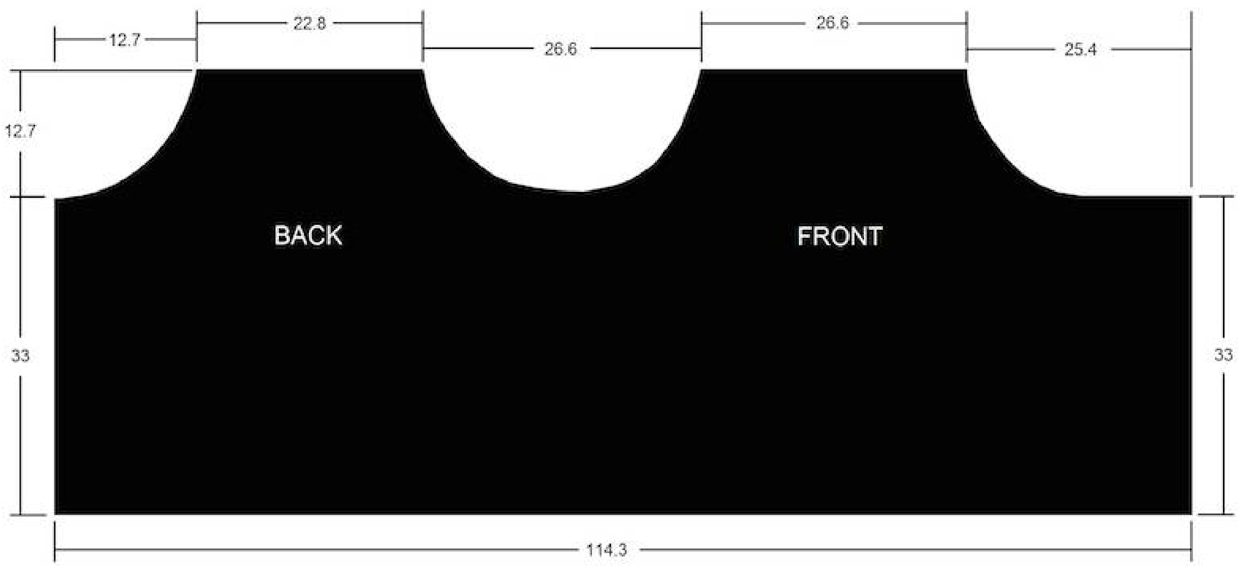

Hand-grown and harvested flax being processed using traditional methods.

that claimed to be handwoven was still made from flax that had been machine-harvested and processed using modern methods, such as treatment with chemicals. To achieve as much historical authenticity as possible, we needed linen made from flax that had been grown, harvested, and processed by hand, using only traditional methods.

We discovered that not many people have the dedication to do this. After much searching, we managed to find a woman who actually grew and harvested her own flax and then spun and wove it into linen, practically in our own back yard – in Fond du Lac, Wisconsin. Later, professors Heidi Sherman and Alison Gates began a project at UWGB in which flax was planted, harvested, retted, dried, broken, scutched, and hackled by traditional methods (previous page), and the resultant fibers spun into thread that was woven into linen.



Simplified pattern for linothorax recreation. All measurements are in centimeters. Pattern is sized for a smaller person with a 100 cm chest.




Applying Rabbit glue with a basting bulb and a putty knife

For the glue, we decided to use adhesives that would have been both cheap and widely available throughout the ancient Mediterranean, so we worked primarily with a glue made from the skins of rabbits. Rabbit glue was actually much easier to acquire than the linen, since artists who paint using traditional methods still prime canvases with it; we ordered it from an art supplies catalogue, and merely needed to rehydrate and heat the rabbit powder in a double boiler. We have also subsequently experimented with a variety of glues, ranging from fish glues to modern PVC glues to good old Elmer's glue.

The two main components of the armor were built up by cutting pieces of linen into the appropriate shape and then gluing the pieces together. In general, we found that the finished product was strongest when enough glue was used to saturate both layers. We allowed the laminated layers to dry, which usually took 8-10 hours, and then


Gluing saturated layers of linen together.

repeated the process until we had the required number of layers. By experimenting, we discovered the ideal tools: a turkey baster to squirt the rabbit glue onto a piece of linen and a putty knife to spread it evenly.

One practical lesson we learned is that it was essential to allow each layer to dry completely before adding the next. When we got greedy and tried to laminate several layers at once, the result was that our damp armor grew a nasty-smelling mold – clearly not what we wanted.

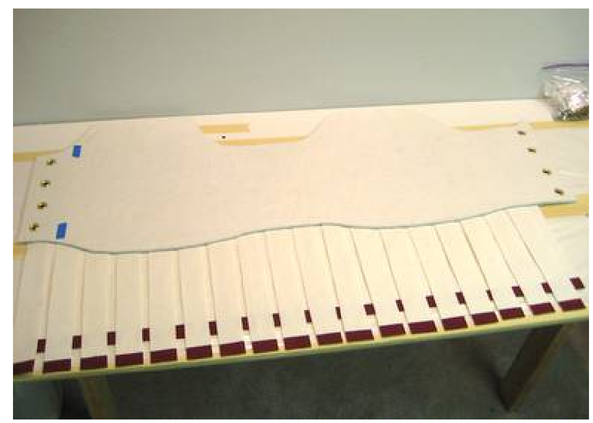
We also figured out – the hard way – that the ancients probably cut each layer of linen to the proper shape before gluing them together. For our first linothorax, we glued together 15 layers of linen to form a one centimenter. thick slab, and then tried to cut out the required shape. This proved nearly impossible. Large shears were defeated. Bolt cutters also failed. The only way we were ultimately able to cut the laminated linen slab was with an electric jigsaw equipped with a blade for cutting through quarter-inch steel plates. At least this confirmed our suspicion that linen armor would have been extremely tough. We also found out that linen stiffened with rabbit glue strikes dogs as an irresistibly tasty rabbit-flavored chew toy, and that our Labrador Retriever should not be left alone with our research project.


Layers of linen glued together to form body and epomides.

Trial and error revealed that the maximum thickness for a slab of laminated linen that would still retain full and repeated flexibility was around 12 mm. Beyond this thickness, over time, the armor began to crack or de-laminate when bent. When the two main pieces reached the desired thickness, they were attached together and *pteruges*, a skirt of thin, laminated fabric strips, were added around the bottom. A few metal fittings, and some decorative painting completed the construction process.

Our first full-scale replica linothorax, had 17 layers and a thickness of 12 mm It required a bolt of linen 16 meters long and 1 meter wide. The lamination process consumed roughly 7.5 liters of glue. This was a rather generously-sized linothorax, fitting individuals of up to 122 cm chest circumference; smaller amounts of materials would have been needed for the average-sized Greek *hoplite* or citizen soldier. The blueprint included in this article (previous page) is a later, slightly simpler design that is sized for a smaller person with a 100 cm chest.

The next step in our investigation was to address the criticism sometimes leveled against such armor: that it could not have offered effective protection to its wearer. To explore this, we made a number of test patches using various types of linens, glues, and weaves, and subjected them to penetration tests by shooting them with arrows under controlled conditions. For these experiments we created dozens of test


Pteruges, fabric strips offering at least some protection to thighs, were added around the bottom.

patches, which were roughly 0.5 by 0.5 meter square, using historically authentic fabric and glues. We focused on arrow tests because, not only would this have been one of the most common battlefield hazards, but it was also a type of attack that we could precisely regulate and measure, producing scientifically valid data.

We tested for a number of different variables, including thickness of fabric, thread count of fabrics, numbers of layers, and alternating the direction of the weave among layers. We also experimented with laminated versus sewn test patches, and even some patches that consisted of quilted layers of linen stuffed with wool.

We hung the patches on a dense foam block to simulate a human torso, and securely strapped them to a heavy wooden stand. Late in the process, when several documentaries were filmed about us by the Discovery Channel, the Canadian History Channel, and the German TV program Galileo, we gained access to a ballistics gel torso, complete with simulated organs and skeletal structure. Happily, the data obtained using this more realistic "body" was nearly identical to our earlier results.

Hand-cast iron and bronze arrowheads, used in the tests had shapes and weights similar to ancient ones from the region..

Patch of laminated material hung on dense foam block simulating a human torso. (left) Measuring penetration. (right)

Our arrows were hand-made wooden ones with natural feather fletching. The arrowheads were hand-cast iron and bronze, sharpened by hand, with shapes and weights similar to those of known examples of ancient Greek, Macedonian, and Persian arrowheads.

We chose to use modern compound bows, which use a system of cables and pulleys to achieve a specific hold weight at maximum draw. This modern equipment was essential to maintain consistency from shot to shot in terms of the power applied to the arrow. Had we used replica wooden or composite bows, then each shot would have varied in power because of discrepancies in draw length, different archers having different pull lengths, and atmospheric conditions such as humidity affecting the resistance of the wood or other natural bow materials. Our bows had hold weights ranging from 25 to 65 pounds, and we took test shots from many different distances varying from 7.5 meters up to very long-range indirect shots fired at an upward angle that then descended toward the target.

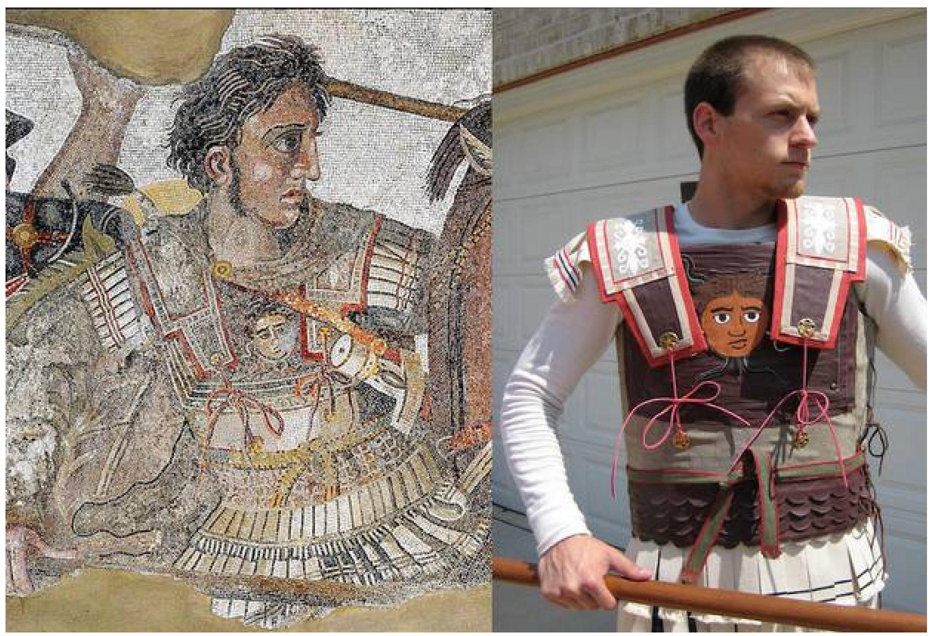
The arrow tests revealed that the linothorax would have provided excellent protection to its wearer. For example, when a 12 mm laminated test patch was shot from 15 meters with a 50 pound pull bow, the arrowhead failed to fully penetrate the test patch. To give an idea of the degree of protection provided by the linothorax, when an arrow was shot at the foam target block without any test patch affixed to it from a very weak 25 pound bow at a range of 7.5 meters, the arrow still had enough power to penetrate an impressive 230 mm deep into the foam target block, clearly a fatal shot if it had struck a human being.

The most important variables turned out to be the thickness of the test patch, the strength of the bow, and the distance from the target. Laminated test patches had about 15% more resistance to penetration than sewn ones – an argument in favor of the lamination technique – while quilted patches stuffed with sheep's wool were relatively ineffective.

We calculated that the force required to penetrate a 12 mm laminated test patch was approximately 70 Joules. In experiments using bronze plates made by a blacksmith to be as close as possible in chemical composition and hardness to ancient bronze, we found that 70 Joules was also roughly the amount of force needed for the same arrow to penetrate bronze armor nearly 2 mm thick. This is the upper end of what the thickness of ancient bronze cuirasses seems to have been.

A number of variables that we thought might make a big difference in resistance to penetration actually did not. The number of layers, density of weave, and the type of glue had only very minor effects. For example, we found that an 8-layer test patch made from coarse linen offered almost the same degree of protection as a 17-layer patch of equal overall thickness made from very fine linen. This means that a completely effective linothorax could have been constructed out of low-quality linen or even an assortment of old scraps.

We believe that the linothorax mentioned in the literary texts and worn by Alexander the Great was a common – and arguably the dominant – subtype of the Type IV armor observed in ancient art, although some were also probably made of leather or a combination of materials. Whether used in its laminated or sewn variants, the linothorax appears to be an extremely viable form of protection, and one that even offers a number of major advantages over metal armor:


Alexander the Great from mosaic. (left) Scott Bartell in modern rendition. (right)

1. Linen is a far more practical material to wear in a hot climate, and would have given soldiers greater endurance, both in battle and on the march. Metal armor heats up quickly, and, under the glare of a hot sun, can quite literally bake its wearer, whereas linen armor stays cool and comfortable.

2. The weight of the linothorax is considerably less than that of metal forms of body armor. Our reconstruction 12 mm thick linothorax weighs about 4 kg. A 2 mm thick bronze cuirass for the same size individual and providing an equivalent degree of protection would have weighed about 10 kg.

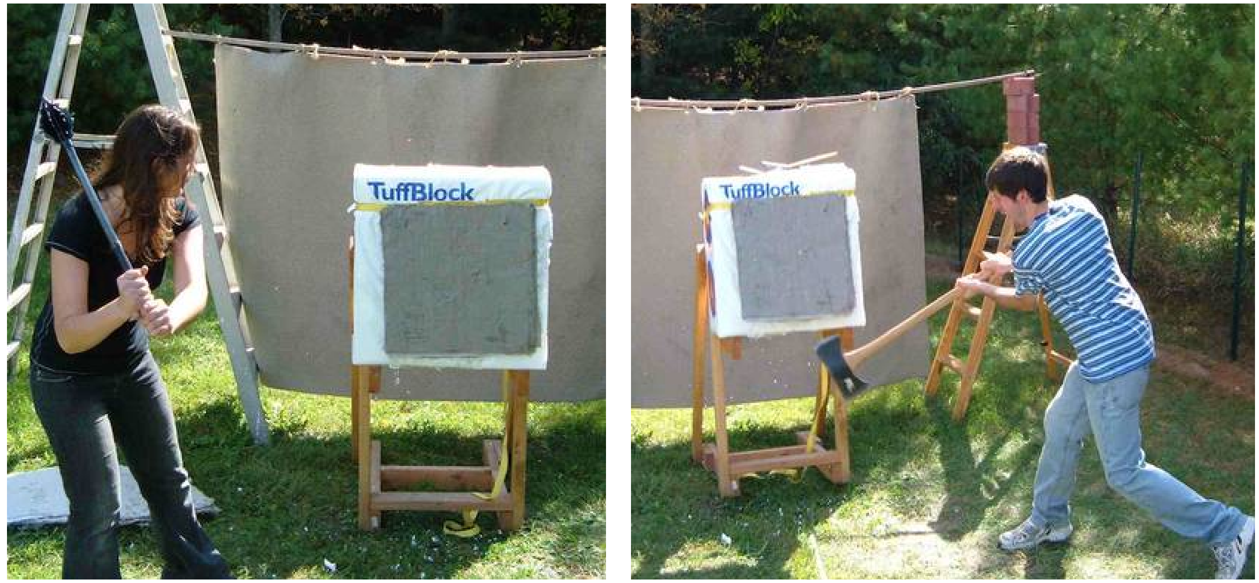
3. When linen gets wet, the tensile strength of its fibers actually increases by about 33% percent, so the linothorax would have functioned well in humid or wet environments. Especially with the laminated variant, this raises the issue of using waterproof glues or else applying a waterproof coating. We found that a test patch coated with beeswax successfully resisted penetration by water even after a 6 hour simulated rain followed by 1 hour of complete immersion in water. Even when one of us wearing an un-waterproofed laminated linothorax was caught in a thunderstorm, we found it resisted penetration by rain surprisingly well. Although a few edges came up as the glue became moist, we pressed them back down afterwards

and they dried in as solid a form as they had been originally.

As a bonus, beeswax-scented armor might have been a pleasant asset in an ancient army full of sweaty, smelly soldiers. In light of the sweet honey-like smell from the beeswax waterproofing, I am tempted to suggest a practical explanation for an otherwise mysterious passage in the biography of Alexander the Great, written by the Greek author, Plutarch. He claimed that Alexander's skin emitted a sweet smell that "permeated all his garments with its fragrance" (4.2). Perhaps it was actually the other way around?

4. The linothorax used materials that were widely available, even to relatively poor inhabitants of the ancient world, and the technical skills needed to make a linothorax, weaving and gluing, were common ones familiar to almost all peoples of the ancient Mediterranean. Rather than requiring the specialized skills of a blacksmith to manufacture or repair it, the linothorax could have been constructed and repaired by quite literally almost any woman or girl in the ancient world.

5. The wide availability of the materials and the skills needed to create a linothorax may have made it significantly cheaper to build than comparable metal armor. They could also have been mass-produced more readily since, unlike a bronze cuirass, a linothorax did not have to be constructed to fit a specific individual. Using the ties at the side and top, a linothorax can easily be adjusted to achieve a fit within a generous range of body sizes.



Students assessing the toughness of a linen test patch with mace (left) and axe (right)..

6. The armor is very wearable. Even at the maximum 12 mm thickness, the linothorax retains flexibility. We found that when we wore it for several hours, our body heat softened the glue somewhat, so that the linothorax molded itself to our particular body shape, making it surprisingly comfortable to wear for extended periods. Finally, the linothorax possesses all these advantages while still providing good protection to its wearer, especially from arrows.

Literary and iconographic sources clearly show that the linothorax, whether laminated or sewn, was used for a long time by many different cultures. Our experiments demonstrate some of the reasons for this popularity, and suggest that it may have been a surprisingly effective form of defense for ancient Mediterranean warriors.

While we subjected our laminated linen patches to hundreds of carefully measured arrow tests, we also engaged in some less scientific testing of their durability. My students enthusiastically stabbed, hacked, slashed, and pounded them with various maces, axes, spears, and swords, helping us to demonstrate what kind of protection laminated linen armor would have provided.

All of this mayhem (both scientifically controlled and free-form) convinced us that our linothorax was ancient battlefield-ready, but we still felt compelled to try a real-life scenario, so as a final test, Scott donned the armor and I shot him with an arrow from 15 feet away. While we had confidence in our armor, our relief was still considerable when the arrowhead stuck and lodged in the armor's outer layers, a safe distance away from Scott's flesh.

While we spent a lot of time and resources to construct a linothorax out of historically authentic materials, and were fairly satisfied that we had achieved this goal, for fun, both my students and I have made other replicas out of cheaper, more modern materials since then.A quite satisfactory linothorax can be made for less than $100 using almost any organic textile, including linen, burlap, and cotton, all readily obtainable from a fabric store.

For glue, we found that Elmer's glue is easy-to-use, performs almost the same as more historically accurate glues, and can be conveniently obtained in gallon jugs from stores such as Home Depot. Since it is water-soluble, it is a good idea, however,to spray the finished armor, inside and out, with a waterproofing spray such as is sold to waterproof boots. The product looks and performs almost identically to our most historically accurate reconstruction.

The aim of our research had been to go back in time, reconstruct something over a millennium old, and experience what it would have been like to use it. The process of doing so has certainly led to some memorable and unexpected experiences for all of us. Visit the [Linothorax Project website]() for more information.

Gregory Aldrete lines up a shot on his student, Scott Bartell, to test strength of linothorax armor. (above) Gregory looks on as Scott shows arrow penetrated only outer layers. (below)

Gregory S. Aldrete *is the Frankenthal Professor of History and Humanistic Studies at the University of Wisconsin-Green Bay. He is the author or co-author of seven books on the ancient Greek and Roman worlds, and has made three video courses with the Teaching Company/The Great Courses. He won the national teaching award from the Society for Classical Studies, and was named the 2012 Wisconsin Professor of the Year.*

Scott Bartell *is an independent scholar who was the originator of the UWGB Linothorax Project and is the co-author of the book, "Reconstructing Ancient Linen Body Armor: Unraveling the Linothorax Mystery." He has co-authored articles and given presentations on his research to a variety of academic and public groups, including winning the 2010 Best Poster prize at the Annual Meeting of the Archaeological Institute of America, the largest international conference of professional archaeologists.*

Alicia Aldrete *is an independent scholar and illustrator, and co-author of two books, "The Long Shadow of Antiquity: What Have the Greeks and Romans Done For Us?" and "Reconstructing Ancient Linen Body Armor: Unraveling the Linothorax Mystery." She holds degrees from Princeton University and the University of Michigan, and is the co-author of several articles on the linothorax project, including a recent one in "Ancient Warfare Magazine."*