

DAVID VERSUS GOLIATH: A ROCKY TALE

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The famous Biblical story of David and Goliath is a mind-blowing tale of a young Israelite shepherd boy who uses his tremendous faith in G-d and a simple sling to single-handedly defeat a Philistine giant [1]. Several scholars feel that the idea of a robustly armored giant conquered by a mere youth armed with only a sling is too difficult to accept. As such, some modern hypotheses have suggested that Goliath suffered from various medical conditions, effectively weakening the giant during his encounter with David [2]. However, most Biblical commentators and scholars do not diagnose Goliath with any medical ailments. In fact, *Rav* (as in *Rav* and *Shmuel* from the Talmud) explains that Goliath was physically perfect [3]. This description would unlikely be associated with a diseased person. Viewing the *pesukim* from a different angle, in fact, makes it completely unnecessary to assume that Goliath's health was compromised at the time of the battle [4]. We may reasonably conclude that despite Goliath's physical fitness and impressive weapons, David cleverly employed the natural laws of physics to defeat the giant.

Before delving into the physics of David and Goliath's battle, it is worthwhile to discuss some important background information to the story. Goliath is first introduced as a Philistine giant and "champion" of war. On behalf of the entire Philistine camp, Goliath arrogantly approaches the Israelites and offers a solution to the standoff between the two armies. However, it is a solution which clearly lies in favor of the Philistines considering Goliath's enormous size and strength. If Goliath is triumphant in battle, then all the Israelites must become servants to the Philistines. However, if an Israelite emerges as the victor, then the consequences are reversed in favor of the Israelites. Essentially, only one life would need to be taken in battle in order to determine the triumphant army [5].

Over the following forty days, Goliath approaches the Israelite army twice a day, once in the morning and once in the evening. The Israelites become more fearful, and Goliath becomes more arrogant as his daily offer to fight any Israelite is gradually transformed from a challenge to a taunt with each passing day [5]. Certainly, Goliath's challenge is easy to make because of his

enormous size and strength. With regard to his height, the *pasuk* says that Goliath was "six cubits and a span." According to *Rav Dovid Qimchi*, a cubit is approximately two feet, and a span is half of a cubit. This means that Goliath was about 13 feet tall [2]. Other sources give Goliath a height of approximately ten feet [6]. Either way, if Goliath were a basketball player today, he could

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easily "slam-dunk" a basketball with his feet flat on the ground [5]. Furthermore, a man of that height could easily weigh close to 500, or even 600 pounds. If Goliath's height was not intimidating enough, then his suit of armor would certainly do the trick. *Pesukim* 6 and 7 describe that Goliath was donned from head to toe in metal armor weighing "5,000 copper shekels." The blade of his spear alone weighed "600 iron shekels" [1]. Converting shekels to pounds, Goliath's armor weighed about 125 pounds and his spearhead 15 pounds [6]. It is very understandable from this viewpoint why the Israelites feared him so much. It would certainly take an extraordinarily courageous soldier to defeat him.

Ironically, Goliath's eventual opponent, David, is not a soldier at all. And when we are introduced to him nothing is described regarding his strength, size, or weapons. It was David's faith and strength of character, and not his appearance, which would make him qualified for the task of bringing down Goliath. David's three oldest brothers have gone out to war with King Saul while David remains at home to care for his father's sheep. However, David emerges on the scene when his aged father, too weak to travel to the army camp himself, instructs David to go to the Israelite camp where he is to bring supplies to his brothers. At the camp, David finds his brothers. As he is speaking to them, he hears Goliath's challenge and his cursing of the Israelites and G-d. As David observes his fellow Israelites cringe in fear of this giant, he hears from the soldiers that King Saul has offered some very generous prizes to whomever volunteers to take down Go-

liath. Apparently, King Saul has promised not only a substantial amount of wealth, but also his daughter's hand in marriage and exemption from taxes for the volunteer's family [5].

David then asks several people around him to confirm what he has just heard. Wouldn't any true soldier of King Saul take advantage of this tremendous privilege to defeat Goliath? After all, this giant is cursing G-d and David has full faith that G-d will give the victory to whomever steps up to the plate. On top of that, the king is offering all these fabulous gifts! Utterly perplexed, David keeps asking around to ensure that what he has heard about King Saul's offer is correct. Why is no one accepting this honorable challenge [5]?

Angered by the sight of his younger brother's inquiries, Eliab, David's oldest brother, ruthlessly cuts into David. "Why have you come down? And with whom have you left those few sheep in the wilderness? I know the wickedness of your heart; for you have come down to see the battle" (1 Samuel 17:28). Actually, in every area where Eliab accuses David of doing something wrong, David's actions were completely innocent and even praiseworthy. David's appearance on the battlefield was prompted by his father's instructions to travel there, and not by childish curiosity as Eliab had accused. David also responsibly appointed a supervisor over the sheep while he would be away. Despite Eliab's insulting and discouraging remarks, David is not deterred by them, and continues asking around to ensure that what he has heard about King Saul's great offer is, in fact, correct [5].

When Saul hears about David's inquiries he summons him to his quarters, where David expresses to King Saul his wish to fight Goliath. Upon noticing David's youthful countenance, King Saul replies that David is too young and, therefore, not experienced enough to defeat Goliath who has been a warrior since his youth. However, David explains that he had killed simultaneously a lion and a bear with his bare hands in a courageous and successful attempt to rescue one of his father's sheep [1]. According to the *Malbim*, David reasoned with King Saul that Goliath's strength would at most be equivalent to the strength of only one of these wild beasts [7]. David proves to King Saul his warrior abilities so convincingly that the king allows David to fight Goliath on behalf of the entire Jewish people. It seems that David's "trivial" duty of caring for his father's flock of sheep has prepared him quite nicely for his upcoming battle with Goliath [5].

Determined and fearless, David goes to a nearby brook to pick up his fatal weapons - five smooth stones. He places the stones in his pouch and heads toward the battlefield, a stick in one hand and a sling in the other. Goliath must have been completely beside himself at the sight of David. Here we have a 13-foot tall

giant, adorned in metal armor from head to toe, confronted by an unarmored youth carrying a stick and, at this point in time, an empty sling. The onlookers must have been overcome with great trepidation and utter confusion. Goliath's likely surprise at the sight of his apparently unprepared enemy quickly turned to disdain as he curses David by his gods and roars that he will deliver David's flesh "to the birds of the sky and the beasts of the field!" David then boldly asserts what is probably one of the most famous Biblical quotes: "You come to me with a sword, a spear, and a javelin, but I come to you in the name of G-d." Goliath had no idea that his physical weapons would pale in the face of David's spiritual ammunition. The battle rapidly ensued and ended as David quickly ran toward the battle line to the Philistine, pulled a stone out of his pouch, slung it, and fatally struck the Philistine in the forehead [1].

Clearly, Goliath should not have underestimated the lethal power of the sling. Although the sling is considered a low-status weapon, it can be very deadly in the hands of an expert. Since the sling requires few resources and is easily produced, it was the preferred weapon among shepherds in the field due to its effectiveness in warding off threatening animals [8]. As such, David, inexperienced with traditional armor and weapons, selected the sling with which he was familiar [4]. In fact, the sling was a commonly used weapon among the Israelite militia [8]. For example, in the Book of Judges it is noted that during war "everyone could sling stones at a hair breadth, and not miss" [9]. The common use of the sling in the Israelite army was due to the sling's effectiveness and ease of production. It is unclear exactly when men first started slinging stones instead of throwing them, but clearly, men learned at some point that stones could be slung with greater speed, range, and accuracy than they could be thrown with bare hands [8].

Stones from riverbeds, as the ones that David took with him to battle, were the most popular due to their polished smoothness. Smooth stones were preferable over edged rocks because they experienced reduced effects of air resistance, enabling greater accuracy and range [10]. In addition to the fact that the stones were smooth, *Rasbi* comments that the stones were also thin [11]. The force of air resistance would be weaker against thin stones as opposed to wider ones [10].

According to literature on weapon history, slung stones could reach speeds up to 90 meters per second. The sling could also achieve an average range of 150 to 500 meters depending on the weight of the stone and the length of the sling. Longer slings could achieve a longer range [10]. Currently, Larry Bray holds the Guinness World Record for slinging a stone projectile (52 grams)

437.1 meters [8]. That's approximately four times the length of a football field. Arguably, ancient slingers who trained since childhood and relied on the sling for survival in battle could approach an even greater range, close to 600 meters [10].

A sling could be made by anyone as its construction did not require any level of real skill as with other weapons such as the bow. Various materials could be used to make the cords and pouch of the sling. Non-elastic materials such as sinew, plant fibers, animal hide, and hair were among the more common resources. At the center of the sling, a cradle is constructed for the placement of the stone. When in use the cradle folds around the projectile. At the end of one cord of the sling, a finger-loop is formed, which is placed over the second finger. At the end of the other cord, it is typical to tie a knot. The knot is held between the index finger and the thumb to be released at the right moment [8].

Even if the stone did not penetrate the armor, it was capable of crushing bones and inflicting a fatal internal injury.

There are several different slinging methods, but the overhand and underhand techniques are the two basic divisions of throwing. In an overhand throw, the sling is swung in a counter-clockwise motion and the projectile is released at the top of the arc from where it travels parallel to the surface of the earth toward the target. In an underhand throw, the sling is swung in a clockwise motion and the projectile is released at the bottom of the arc. In both slinging techniques, the slinger should perform various body motions in the direction of the target in order to add as much speed to the sling missile as possible. Range is believed to be increased with the underhand method, but it is more difficult to master in terms of accuracy. However, some archaeologists feel that once mastered, the underhand motion was the optimal way to use the sling. Another slinging method is to whirl the sling in a circular motion over the head. Regardless of which method is used, a skillful throw may require just one rapid rotation of the sling [8].

We do not know which sling technique David used. However, regardless of the method that he utilized we may assume that after loading the stone in its cradle, David began to whirl the sling in a circular orbit. While the sling was subjected to a circular motion, the stone exerted a force on the cradle, tightening the cords of the sling. The basic physical principle that played a role here is

that a force is necessary for maintaining the motion of an object to a circular path [12].

Another important point is that while centripetal acceleration (that is, acceleration toward the center) guarantees circular motion, tangential acceleration increases the magnitude of the tangential velocity. As such, the tangential velocity went from zero meters per second to a very large value as David whirled the sling [13].

David probably made no more than one or two rapid rotations of the sling, and with Divine timing, released one of the sling's cords to set the projectile into its fantastic motion. The stone embarked on a parabolic trajectory toward Goliath's forehead. With only the slight force of the Earth's gravity and negligible air resistance to compete with, the stone struck Goliath with deadly force. Here we have another important physical principle that came into play. The moment that the constraining force is removed, the object will move along a tangent of the circular orbit. Highly skilled with the sling, David released the projectile on a perfect path toward his target [12, 13].

It is curious what force the stone had when it penetrated Goliath's skull. The force must have been quite strong, but considering that accurate data and measurements cannot be acquired, only very rough approximations will be used to estimate it. The tangential velocity of the stone in its circular orbit may be calculated by taking $2\pi r/T$, where r is the radius of the circular path, and T , the period, is the time it takes to complete one rotation [14]. However, this formula is not very useful here for several reasons. The slinger engages in all sorts of body motions to increase the speed of the stone just before releasing it from the sling [8]. One of the most important body motions is probably the extremely quick flick of the wrist which the slinger performs just as he is releasing the stone. This quick flick of the wrist increases the velocity of the stone exponentially. Furthermore, the *pasuk* informs us that as David approached the battle line with sling in hand, he ran, increasing the velocity of the stone even more [6].

It has been shown that a stone can be released from a sling with a speed that is much greater than the speed of a baseball thrown by a professional baseball pitcher - approximately 100 miles per hour [6]. This translates to a velocity of 45 meters per second. According to the literature, slung stones could reach velocities of 90 meters per second [10]. We can assume this literature value for the velocity of the stone that David slung; consider David the champion baseball pitcher of the Jewish leagues. We may also assume that the velocity of the stone remained constant in the horizontal direction assuming negligible air resistance and a relatively short distance between the two warriors. The gravitational force only changes the vertical velocity accelerating the

projectile down. However, it will be assumed that most of the stone's velocity was confined to the horizontal path of the projectile. To get the force that the stone exerted on Goliath's forehead, we take the momentum of the stone and divide it by the time taken to penetrate the giant's forehead starting from the moment that the stone made contact with his flesh. Momentum is defined as the product of the object's mass and velocity [13]. The mass of a typical stone used for slinging was about 50 grams (5×10^{-2} kilograms) [8]. However, stones with mass of up to 500 grams were often used as well [8]. The product of the stone's mass (assumed 5×10^{-2} kilograms) and velocity is therefore equivalent to 4.5 kilogram meters per second. Having in mind that the velocity of the stone was approximately 90 meters per second, some simple calculations show that it would have probably taken less than 1 millisecond to penetrate one inch through Goliath's forehead. However, since the stone's velocity rapidly decreased as it penetrated the giant's forehead, a penetration time of 3 milliseconds will be assumed. The force of the stone would then have been approximately 1500 Newtons [13]. This force is approximately one-sixteenth the force of a typical handgun bullet through a human skull (which is 25,000 Newtons assuming a bullet speed of 300 meters per second and a penetration time of slightly more than half of one millisecond) [15]. This is an enormous force, and it was applied in an instant over a small area. Similarly to a karate expert's performance in breaking slabs of concrete, a large amount of force applied over a short time in a small area will result in maximal damage [6].

It may be more useful to solve for the pressure that was exerted by the stone on the giant's forehead. Pressure is defined as force per unit area. Having already solved for the force, the area remains to be calculated. The surface area of a circular object is πr^2 , where r is the radius of the circle. Ancient stone projectiles were approximately 43 millimeters in diameter (0.043 meters), comparable to a golf ball. Assuming this diameter, the radius was 0.0215 meters. Substituting this value into the formula for surface area of a circle, we get 0.00145 meters². Dividing the force, 1500 Newtons, by this value gives the pressure that the stone exerted on the giant's forehead - approximately 1.0×10^6 Newtons per meter² [13]. Such an enormous pressure would certainly have been enough to puncture the giant's forehead even though his skull was probably thicker than an average human's. According to one source, a pressure of 2.5×10^5 Newtons per meter² (36 pounds per square inch) is sufficient to crush a human skull [16].

Now that we have established that the stone had sufficient force and pressure to penetrate Goliath's forehead, we are still left with a puzzling question. The *Navi* relays that Goliath was

covered from head to toe in metal armor. Considering Goliath's apparent conscientiousness in covering his entire body with armor, it is almost unreasonable to suspect that he would have entered battle without protective gear on the most delicate part of his body – his head. Many depictions of ancient battle scenes show that helmets were designed to cover the top and sides of the head, but not the forehead. This would have effectively exposed Goliath's forehead to the stone. However, the *Radak* assumes that Goliath must have been wearing a helmet with a shielding area over the forehead. According to several explanations offered by the *Radak*, something clearly went wrong (or rather right) despite the helmet's completely protective design. The *Radak* first tries to reconcile the problem by pointing to an event that immediately preceded David's slinging of the stone. Goliath roared that he would deliver David's flesh to the birds of the sky. In doing so, he looked up and pointed skyward. As a result, the part of his helmet that protects the forehead slid back and rested on top of his helmet, exposing his forehead to the deadly stone. The *Radak* also suggests that perhaps there was a small exposed space in Goliath's helmet that was still large enough to allow the stone to pass through. David may have slung the stone with such perfect accuracy that it entered this small exposed space in Goliath's helmet. Another explanation suggested by the *Radak* is that the stone penetrated both the metal helmet and Goliath's forehead [17]. Strictly using the natural laws of physics, this method of penetration into Goliath's forehead is unlikely. However, it should be noted that this explanation is based on *Midrash*, which does not always serve to be taken literally.

Still, the impact of a slung stone should not be underestimated even in the presence of shielding armor. Vegetius, a Roman writer in the 4th century, once observed that "soldiers, despite their defensive armor, are often more aggravated by the round stones from the sling than by all the arrows of the enemy" [10]. Even if the stone did not penetrate the armor, it was capable of crushing bones and inflicting a fatal internal injury. Certainly, unarmored bodies were easily penetrated by sling missiles. In fact, an ancient medical textbook, discovered in an archaeological dig, included instructions for removing sling missiles from wounded soldiers [18]. Further demonstrating the power of the sling, an observer recorded during the Spanish conquest of the Aztec empire in the 15th century that an Andean slinger could shatter Spanish swords or kill a horse in one hit! In fact, almost until modern times, slings could be used quite successfully against Spanish firearms from a distance of 50 yards. The last recorded martial use of the sling was during the Spanish Civil War in 1936, which is very recent considering the ancient origins of this weapon. Although its use

requires tremendous skill, the sling's power, range, and accuracy enabled its effectiveness as a deadly weapon of war even up until relatively recent times [10].

It should then remain little wonder why David chose the sling as his weapon against Goliath. With knowledge of the sling's advantages and a skillful technique, David must have figured it was the optimal weapon of choice. Since the stone, in fact, penetrated Goliath's forehead, David was obviously correct in his judgment. While all the onlookers were probably in shock after observing David's spectacular feat, the immediate aftermath of the stone's contact with Goliath's forehead seems to be almost equally puzzling to some Biblical commentators. With the stone having enough force to penetrate Goliath's forehead, one might predict that the impact would have sent the giant falling backward. Yet, the *pasuk* informs us that Goliath fell forward. Troubled by this apparent contradiction, *Rashi* explains that G-d deliberately orchestrated this peculiar occurrence in order to reduce David's burden when he would eventually run over to the unconscious giant to cut off his head. Had Goliath fallen backward, David would have had to walk an additional distance of twice Goliath's height in order to reach the giant - one time his height for not falling forward and one time his height for falling backward [19]. This explanation may suggest that *Rashi* did not believe that natural laws could explain why Goliath fell forward. As such, an explanation involving G-d's obvious intervention was required. The *Malbim* on the other hand implies that this part of the story does not require an explanation involving an obvious miracle. The *Malbim* seems to believe that while the force of the stone was strong enough to puncture Goliath's forehead it did not necessitate a backward fall. Goliath's fall was less a result of the stone's momentum than the giant's physical weakness, an immediate result of the stone's impact [20]. In support of the *Malbim's* view, it is currently understood that gunshot victims frequently collapse, when shot, due to physical damage or weakness and psychological effects rather than the momentum of the bullet [21]. It is also possible that even after

the stone sank into the giant's forehead, Goliath still had some forward momentum carrying his body forward until collapsing to the ground moments later [6].

It is worth noting that the stone's force did not need to be strong enough to actually kill Goliath. It only needed to be strong enough to knock him unconscious. According to the *Malbim* Goliath still had "*ruach chaim bo*," "the spirit of life in him," even after the stone penetrated his forehead. The giant did not actually die until David cut off his head [22]. From this point of view, the role of *derech hateva* in Goliath's demise is even more convincing.

While David certainly could have defeated a 13-foot tall giant using the physical laws that govern our world, the suggestion in no way undermines G-d's presence at this battle. G-d's Providence can certainly operate through the natural laws of the world. In fact, several Biblical commentators, including the *Malbim*, approach Biblical text with this outlook. According to the *Malbim*, the fact that David struck the giant at all, let alone on his first try, demonstrates G-d's profound presence during David and Goliath's encounter [20]. Had David used all five stones that he carried, and struck Goliath only with the fifth stone, the feat still would have been tremendously impressive.

Another important point is that many people probably think that the only miracle of this story is David's defeat of Goliath. However, we cannot forget all the obstacles that David had to deal with even before he confronted the giant. First, David was not even part of King Saul's army. He was left to supervise his father's sheep several miles away from the battlefield. David also had to get past his oldest brother, Eliab, who made some very discouraging remarks toward David to say the least. Finally, David needed King Saul's official approval to fight Goliath [1, 5]. Clearly, Divine intervention was required in order to orchestrate the events just leading up to David's presence on the battlefield. "A man after G-d's own heart" (1 Samuel 16:7), David then courageously employed the laws of physics to carry out G-d's will and bring salvation to the Jewish people. ■

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