Arrow Lethality Study Update – 2005
Part VI
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The Heavy Bone Threshold

"Adequate penetration appeared to require a total arrow mass of at least 650 grains if any bones at all were encountered." This quote is from the original Natal Study, and dates back a quarter century. When that study was conducted, analysis of data was by hand. It is amazing that the above information surfaced from the data. With all the information amassed since then, and the capacity to sort and analyze data with computer assistance, the only change is that the statement should read "heavy bone" instead of "any bone".

When heavy bone is hit; ribs of the larger species; or the scapula, femur, humerus, or spine of smaller species; an arrow of *approximately* 650 grains total mass penetrates the bone with a significantly higher frequency than an arrow below this total weight. This 'heavy bone penetration' demarcation line is not highly altered by arrow impact-force; certainly not to the degree one would expect.

Chart 9
Non-extreme FOC arrows with mass < or = 700 grain & impacting entrance rib:
All shafts; All Broadheads
2004-2005 Asian Buffalo Testing
N_{Total} = 87

Arrow Mass	Average Pen.	Average Impact Kinetic Energy	Average Impact Momentum	% Penetrating Entrance Rib	% Reaching Exit Rib	% Lethal
<400	9.70	78.59	0.52	44.4%	11.10%	33.00%
<500	8.91	63.05	0.47	50.0%	10.70%	35.70%
<600	9.32	51.63	0.45	51.1%	10.60%	29.80%
<700	10.78	46.14	0.46	65.5%	16.90%	42.50%
550-600	10.03	31.50	0.49	55.0%	11.10%	22.20%
600-650	12.09	34.43	0.44	60.0%	20.00%	40.00%
600-700	12.50	39.70	0.48	80.0%	25.00%	57.50%
625-700	12.13	40.37	0.49	80.6%	25.00%	58.30%
650-700	13.61	41.45	0.49	93.3%	26.60%	63.30%

Chart 9 shows how the data indicates the presence of this threshold. The first four rows are cumulative mass weight groups. The groups for: (1) all arrows less than 400 gr.; (2) all less than 500 gr.; and (3) all less than 600 grains; show little difference in average penetration, frequency of bone penetration, or percentage of lethal hits. When the upper range is expanded to include all arrows below 700 grains an abrupt change occurs; penetration on buffalo ribs (definitely a “heavy bone”) jumps approximately 15%. This indicates a major change in outcome frequency when the arrows having 600 to 700 grains mass were factored into the averages.

The next five rows of the chart are a refinement of data in the proximity of the change. This helps define the exact point at which the change occurs. Comparing the 550-600 grain group with the 600-650 gr. group there is a 20% increase in average penetration with the higher mass group, but only a 5% increase in the frequency of the entrance rib being penetrated.

Comparing the 600-700 gr. group with the 600-650 grain group shows little change in average penetration, but a 20% difference in frequency of penetrating heavy bone. This indicates that a major bone-breaking influence is being exerted somewhere near or above the 650 grain level.

Narrowing the range, little difference in heavy bone penetration frequency is noted between the 600-700 grouping and the 625-700 gr. group. The influence on the frequency of bone penetration is exerted somewhere above the 625 grain range.

When the 650-700 grain range is compared to either the 600-700 gr. group, or 625-700 gr. group, the frequency of heavy bone penetration shows a 13% increase. More definitively, the “heavy bone penetration frequency” shown by the 650-700 grain group is equivalent to that for all arrows/all broadheads having a mass weight equal to, or greater than, 700 grains.

These comparisons are typical of results obtained during all testing for the last quarter century. The data indicates that, *on heavy bone impact*, arrows with a mass less than 600 grains have approximately a 50% chance of penetrating. Between 600 and 650 grains the frequency is nearer 80%. In the 650 to 700 grain total-mass-range the arrow will penetrate a heavy bone on better than 9 out of every 10 hits.

Chart 9 includes all broadheads; all shaft-diameter-to-ferrule-diameter ratios; and all shaft materials. The existence of this ± 650 gr. threshold shown by the data does not, however, mean that broadhead or shaft selection has no bearing on the ability to penetrate heavy bone. It does.

With a given broadhead, shaft material and shaft diameter, but differing arrow mass, the frequency of penetrating heavy bone gradually increases until approximately 650 grains of mass. Near that point, the frequency of penetrating heavy bone rises abruptly. Different broadheads show different *degrees* of increases in frequency, but all show an abrupt increase. This consistently occurs, and must be viewed as a coherent trend.

I can only propose what I feel is the most plausible explanation for the existence of this phenomenon, which I have named “the heavy bone threshold”. It is *theorized* that a mass weight of approximately 650 grains represents a threshold level of arrow mass which permits a *time of impulse* sufficient for breaking most commonly encountered heavy bones. In other words, it allows the arrow to exert whatever amount of force it carries upon the bone for a long enough period of time to breech the bone’s structural integrity.

An analogy would be to place a bowling ball on a level floor and strike it with a short, but forceful, jab of one’s fist. It moves a distance. Now shove the bowling ball with a long, gently shove, of sufficient force to roll the ball. With which does the bowling ball move further? Unless the hard blow is *enormously* more forceful, the bowling ball moves a greater distance with the gentle shove. The difference in the bowling ball’s movement results from the *time* each force acted upon the bowling ball. Applied for a longer period of time a lesser force can accomplish more “work” than a much greater force briefly applied.

To relate the time of impulse directly to penetrating bone it is easier to understand if one thinks in terms of bone flexibility. Arrow “A” strikes a bone with a given force. As it strikes the bone flexes, as do the cartilaginous bone attachments, absorbing the arrow’s force.

Arrow “B”; having the same force as arrow “A”, but with a higher portion of that force derived from its mass; strikes the same bone. As it strikes the bone bends. But arrow “B” is ‘heavier’. It takes longer for it to stop. Its force is applied to the bone for a longer period of time. If the increased bending of the bone is great enough to exceed the bone’s tensile strength (flexional limit), the bone gives way.

The existence of this heavy bone threshold is an interesting feature. The data indicates that an arrow whose mass is approximately 650 grains, shot from a 45 pound bow, penetrates heavy bone with a frequency virtually identical to a like arrow fired from an equally efficient bow of 55 or 60 pounds. With like broadheads, it is more likely to penetrate heavy bone than a lighter arrow striking with significantly greater impact force.

Though the frequency changes with different broadheads the trend remains. One broadhead may show a different frequency of penetrating bone than another, but the threshold is manifest for both, and is uniformly in the *vicinity* of 650 grain total arrow mass.

This threshold relates only to the breeching of heavy bone. Overall penetration, once a bone is breached, is closely related to both momentum and mass (when all else is equal between two arrows). A vast amount of the total available force carried by arrows at this threshold level of mass is expended in penetrating heavy bone. Threshold dynamics distinctly demonstrates how arrow mass influences the impulse of force.

Investigation of the penetration characteristics of extreme FOC arrows is in its early stages. They may show a shift in the required mass to achieve the heavy bone threshold, but early data *suggest* that, if a shift does occur, it may be very-very slight.

Chart 10
Extreme FOC Arrows and Heavy Bone Penetration
All Rib and Scapula Hits; Single Blade Broadheads Only
2004-2005 Asian Buffalo Testing
$N_{Total} = 52$

Arrow Mass Range	Average Mass	Average Impact Kinetic Energy	Average Impact Momentum	Average Penetration	% Penetrating Entrance Bone
<625	597	34.09	0.43	14.75	71.4%
625-700	657	36.53	0.46	17.98	95.2%
700-800	Nil Records				
800-900	844	36.45	0.52	18.91	100.0%
900-1000	927	35.77	0.54	20.89	100.0%

Chart 10; for all *Extreme FOC* arrows having single blade broadheads, impacting either buffalo rib or scapula; shows the frequency of bone penetration by arrow mass weight. In making comparisons between Charts 9 and 10 it must be remembered that variance between the data sets is significant, with the Extreme FOC arrows all having “best quality” broadheads and favorable shaft-diameter to ferrule-diameter ratios.

Chart 9 includes all broadheads; all shafts; and all shaft-to-ferrule-diameter ratios. The frequency of heavy-bone penetration shown for Extreme FOC arrows at the various mass levels may decrease when a wider broadhead selection is introduced. The heavy-bone penetration frequency shown for Extreme FOC arrows does not differ significantly from normal and high FOC arrows of comparable mass when the data is limited to only “best quality” broadheads and favorable shaft-to-ferrule diameter ratios.

Broadhead selection notwithstanding, Chart 10 is *strongly suggestive* that the heavy bone threshold is also present for Extreme FOC arrows; and its location is not very distant from the 650 gr. total mass level shown by non-extreme FOC arrows.

This sixth part completes the study updates through the 2005 testing year. Many topics of inquiry remain for investigation. Future updates will be forthcoming as information warrants.