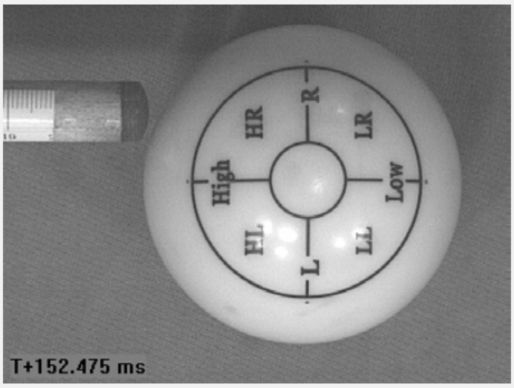
Hard or Soft Billiard Tip: Which One to Choose?

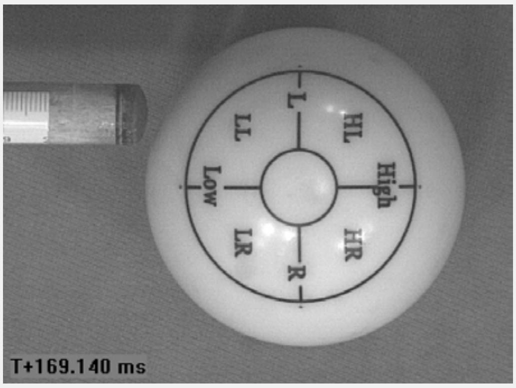
A.Sorokin
April 2023

More than 200 years have passed since the invention of the billiard tip, but the debate about which one is better has continue to this day. Every billiard fan has their personal preferences**:** some like hard tips, others – medium or soft ones. The tips can also be single-layer and multi-layer, made of deer, elk and bison, or buffalo skin. In a word, a huge field for experimentation and opinions. In this article, we make an attempt to understand some of the properties of billiard tips, using quantitative measurements of the translational and angular velocities of a billiard ball, rather than relying on relying not on subjective sensations.

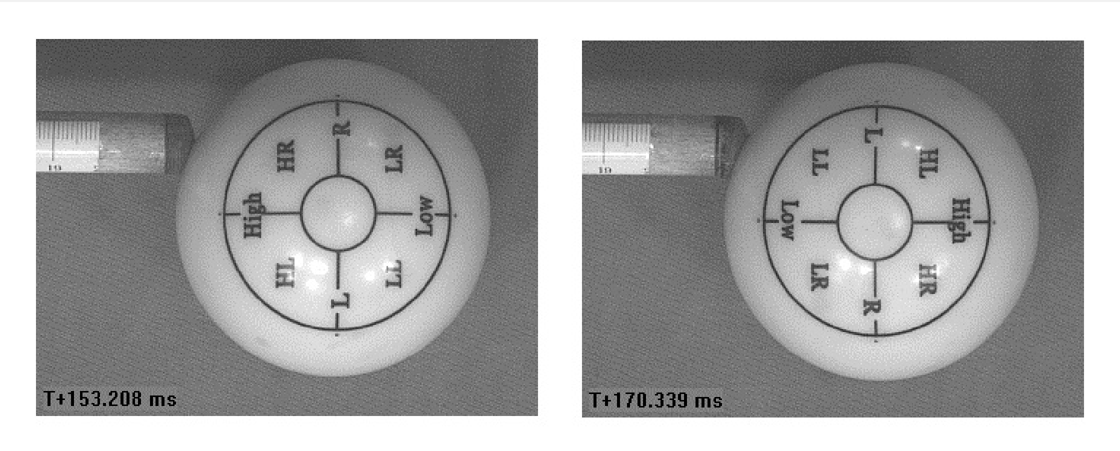
A digital high-speed monochrome camera Phantom V12 with frame rate of 30,000 fps was used to shoot strokes with the same cue but different tips attached to it. All strokes were performed with the same cue speed and with the same offset of the cue axis relative to the center of the cue ball (to the extent the cue testing machine allows). The cue speed at the moment of the cue ball striking was 4.69 m/s, the offset was 15.2 mm.

Below there is a GIF animation of a cue stroke with a hard Kamui Black H tip and a similar stroke with a very soft Rocket tip.



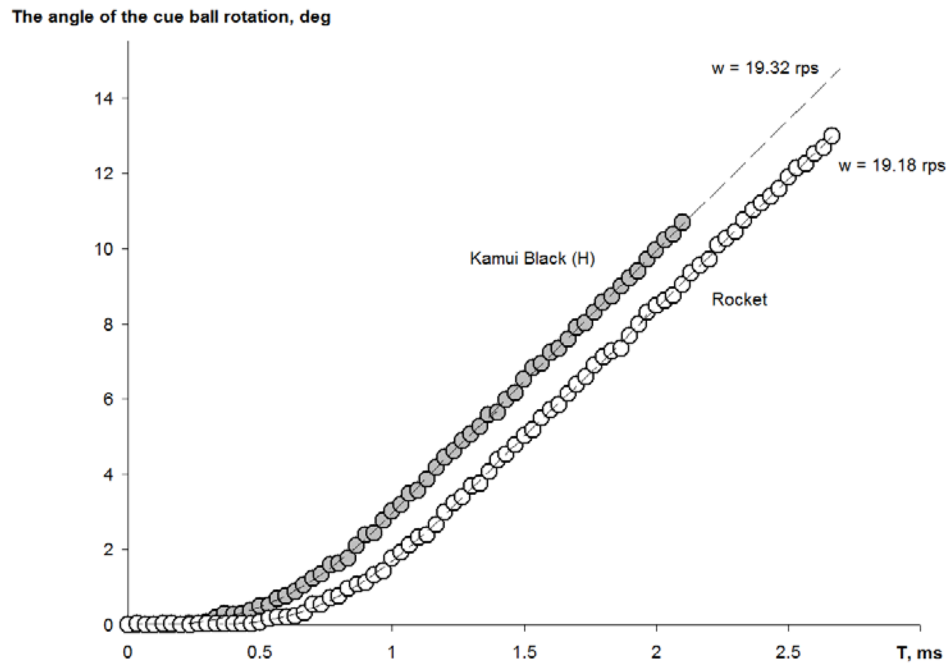


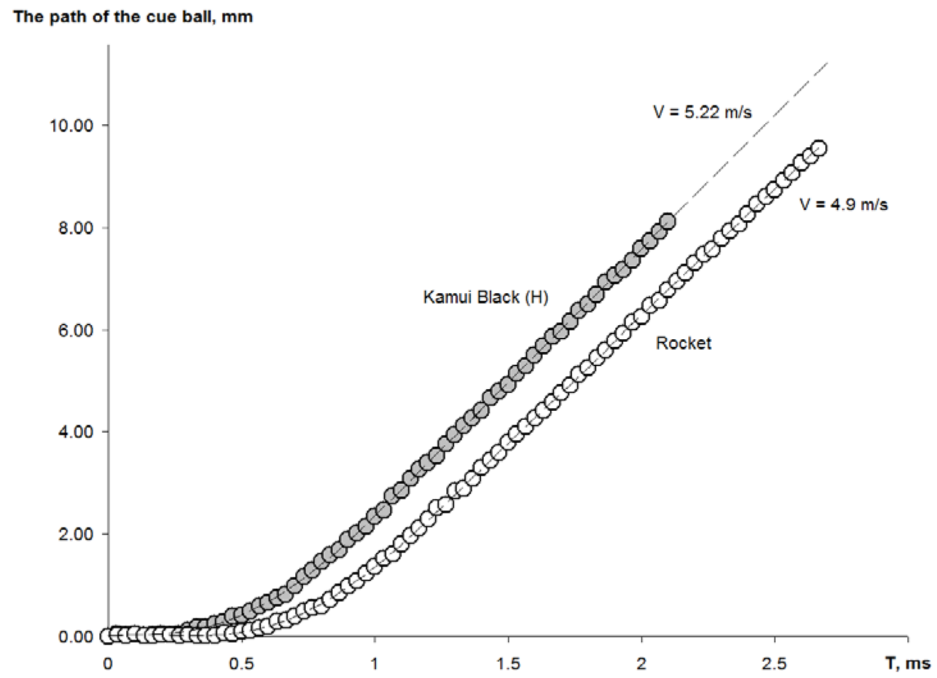
The first thing that catches the eye is the difference in the size of the contact spot at the moment of maximum compression of the tip. For Kamui Black H, the contact spot is about 5 – 6 mm in diameter, while for Rocket it is as big as 10 mm.



The second difference is the different duration of the contact of the cue and cue the ball. For Kamui Black H, the duration is 1.37 ms, for Rocket – 1.93 ms.

Furthermore, for each frame of high-speed shooting, it is possible to accurately determine the cue ball path and its spin angle during the stroke, as below:





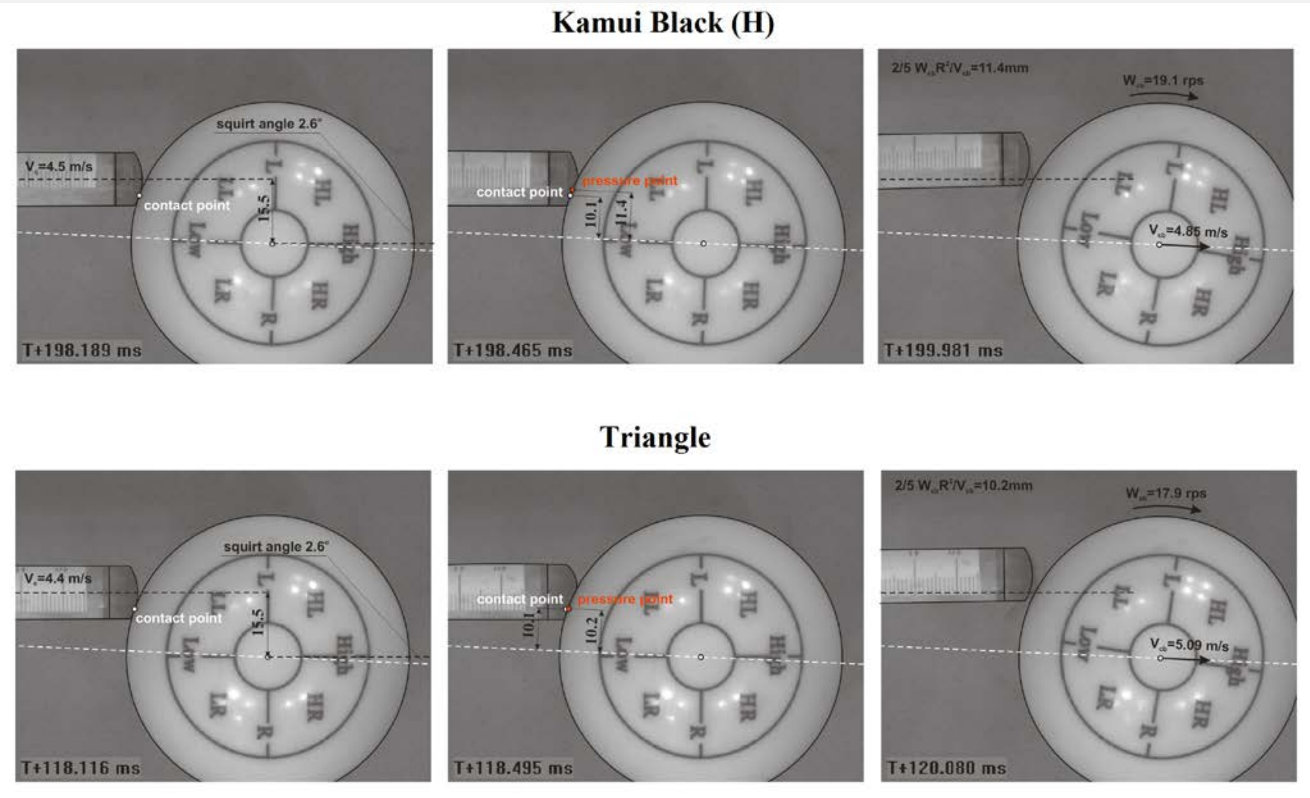
The dark circles belong to the Kamui Black H tip and the bright ones belong to the Rocket. The time of the contact is shown by the horizontal axis, T = 0 corresponds to the moment of contact between the tip and the cue ball. A close look at these graphs reveals that, until the tip is completely compressed, the cue ball does not move and does not rotate. It means that the elasticity of even a solid tip is so small compared to the inertia of the ball, that it is not possible to determine the movement and rotation of the cue ball even on high-speed video. This is a very interesting fact, and, as far as I know, no one has paid attention to that before. It is interesting, first of all, because it invalidates all ideas about increasing the ball rotation speed by increasing the contact time. The movement and rotation of the cue ball begins only when the compression of the cue stick itself begins. As the cue compresses and straightens, the angular and translational speed of the cue ball increases. After the cue and cue ball separate from each other, the angular and translational velocity of the latter remains almost unchanged, that is clearly seen by the way the measurements perfectly form a straight line. From the angle of inclination of these straight lines, it is possible to determine the numerical values of the angular and translational velocity of the cue ball after impact. For a solid Kamui Black H tip, the translational velocity V is 5.22 m/s, and the angular velocity w is 19.32 rpm. For the soft Rocket tip, both speeds are smaller: V=4.9 m/s**;** w=19.18 rpm. This means that a portion of the impact energy on the cue with a soft tip has dissipated into heat, vibrations of the cue, etc.

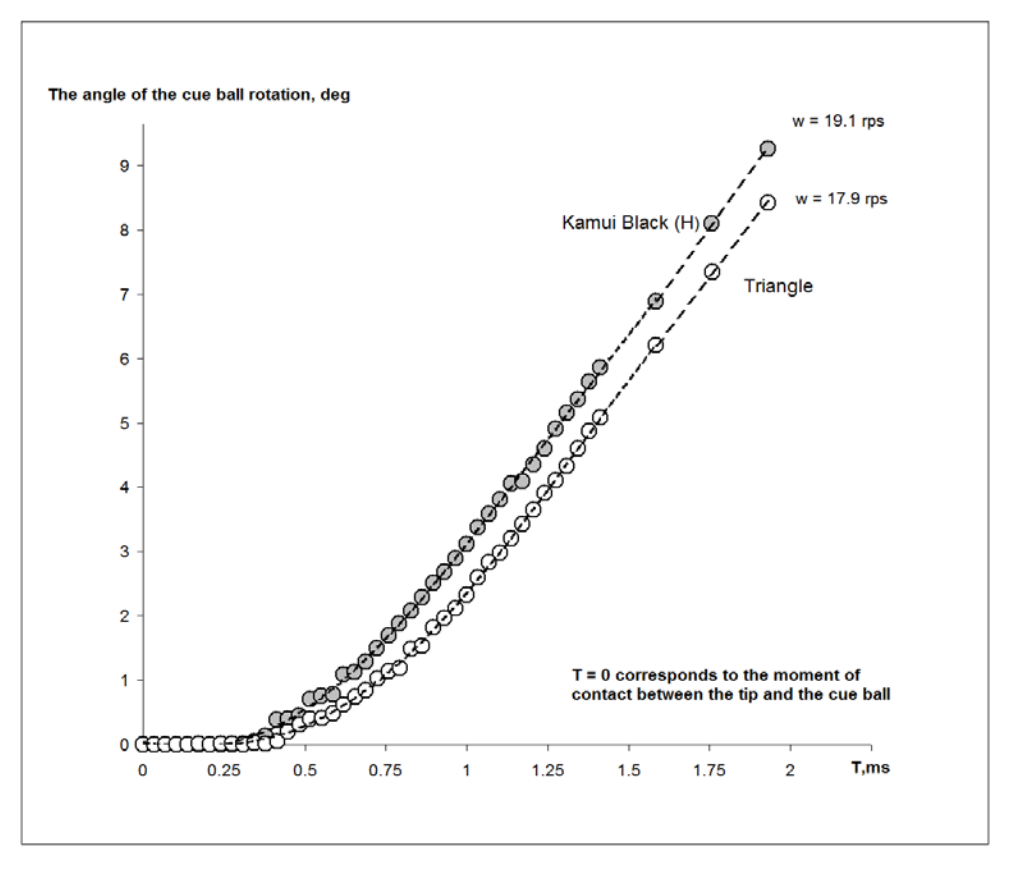
From here, one could make a hasty conclusion that a solid tip «twists» the ball better, but this is not entirely true. The fact is that in most cases, the absolute values of angular or translational velocity themselves do not matter much, unless the goal is to make a burn mark on the cloth with a rotating ball, break the cushion, or perform some crazy «cosmic» shot. In billiard games where the cue ball control prevails over the power pocketing, it's not the cue ball angular velocity that matters, but the ratio of this angular velocity to the translational velocity, i.e., w/V. Digging a little deeper into physics, one can see that the ratio w/V is nothing else (up to a constant multiplier) than the offset of the cue contact point relative to the center of the cue ball. For the Kamui Black H hard tip, this velocity ratio is w/v=19.32/5.22=3.70, and for the Rocket soft tip w/v=19.18/4.88=3.93, that is, 6% more**;** it is not a lot, but also not negligible.

Here a legitimate question arises: how did it happen that the cue offsets for both tips are the same, but the speed ratio is different? Most likely, this is due to the fact that during the impact, the tip does not touch the cue ball at one point, but a rather large contact spot is formed. At each point of the contact spot, a certain force acts on the cue ball from the cue side, at different points – different forces. Scientifically speaking, there is a pressure plot in the contact spot. If, for each point of the contact spot, we determine the magnitude of the applied force and the offset of this point relative to the center of the ball, we can determine the resulting force and the point of its application on the ball (i.e., find the center of pressure). This computational procedure is similar to how the center of gravity of a body, lift and pressure center on an airplane wing are searched for, etc. The pressure center determined in this way does not have to be in the center of the contact spot at all, its position is determined by the physical properties of the tip, its geometry, etc. Therefore, even for the same offsets of the cue axis relative to the center of the cue ball, the position of the pressure center is different for different tips. Since the center of pressure is the point where the resulting force is applied, the position of the center of pressure is the *actual or «effective»* offset that determines the angular and translational velocity of the cue ball.

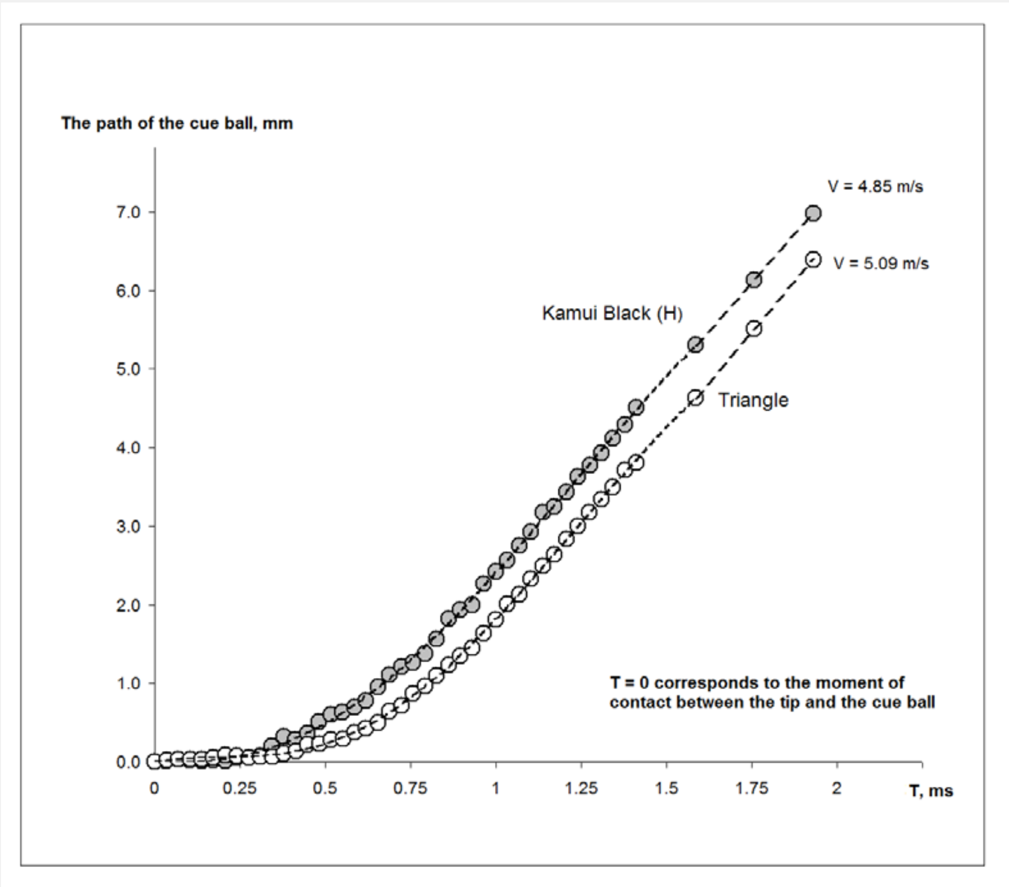
Now a new question arises: how to determine the position of the pressure center for each tip? Obviously, one could start measuring the tip elasticity, hardness, and many other parameters, and then try to write some equations describing the deformation of the tip. However, this is a difficult task, and it’s also complicated by the fact that during the impact the cue ball turns, the contact spot changes, the pressure plot changes. All these pitfalls can be avoided by calculating the positions of the pressure center from the measured values of the cue ball angular and translational velocity at the end of the stroke. As mentioned above, the ratio of angular velocity to translational velocity is the actual offset of the point of application of the resulting force relative to the center of the cue ball b=(2/5*R*R)w/V, and here automatic averaging occurs over the entire contact duration. For the hard Kamui Black H tip, the effective offset of the center of pressure, relative to the center of the cue ball, turned out to be equal to b = 10.74 mm, and for the soft Rocket tip, b = 11.40 mm. This is equivalent to the fact that, when hitting a soft Rocket tip on the cue ball, the blow has struck almost 1 mm higher than when hitting a cue with a Kamui Black H tip.

This result does not imply that all soft tips behave the same way, compared to the hard ones. Below there is the result of a similar comparison of a solid Kamui Black H tip and an ordinary (not pressed) Triangle tip.





The angle of the cue ball rotation, deg
w = 19.1 rps
w = 17.9 rps
Kamui Black (H)
Triangle
T = 0 corresponds to the moment of contact between the tip and the cue ball
T,ms
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
1
2
3
4
5
6
7
8
9

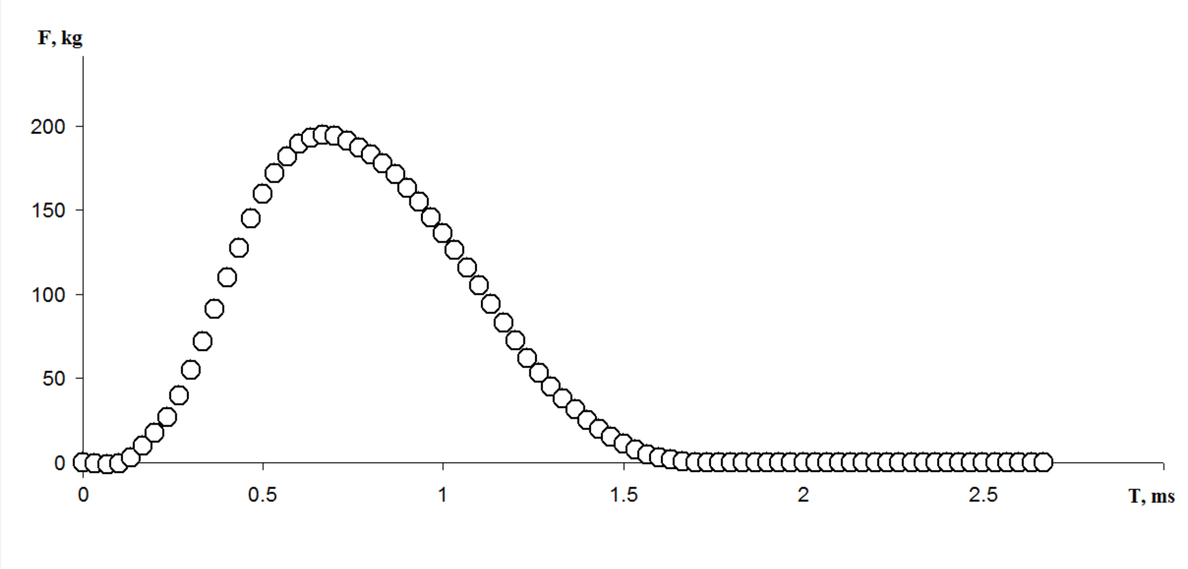


The path of the cue ball, mm
V = 4.85 m/s
V = 5.09 m/s
Kamui Black (H)
Triangle
T = 0 corresponds to the moment of contact between the tip and the cue ball
T, ms
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0

In this case, the hard Kamui Black H tip «wins» more than 1 mm from the softer Triangle tip.

It is most likely that the distribution of stiffness along the tip diameter is what determines the outcome, rather than the tip stiffness. I.e., if the center of the tip is stiffer than the edges (this can be achieved by a certain way of crimping the tip), then it makes sense to assume that the center of pressure will be shifted closer to the cue axis, which will lead to an increase in the actual offset relative to the cue ball center, and, consequently, to larger values of the ball angular velocity relative to the translational one. Apparently, this is associated with the concept of a tip «overspins». If the periphery of the tip is more rigid, then the actual offset decreases, and such tip «twists» less.

It would be possible to put an end to this, but, as always, there are nuances, and, as you know, «the devil is in the details». The above discussion does not take into account the deformation of the cue during the impact, but the forces on the end of the cue during the impact are enormous. Take the data to measure the movement of the cue ball during the impact (the second graph at the very beginning), approximate these values of a smooth curve, calculate the first derivative (i.e., find the values of the instantaneous velocities of the cue ball), then the second derivative (find the acceleration values), and then calculate the magnitude of the resulting force at the center of pressure. That is how it looks on the example of a soft Rocket tip for a medium-strength stroke:



One can see that the maximum force exceeds 200 kg. If we take into account that the force is applied with an offset from the cue axis (see the position of the center of pressure on the tip), then it is clear that such a force will lead not only to longitudinal compression of the cue, but also to its bending. Moreover, the farther the center of pressure is from the cue axis, the greater is the bending moment. Whether it is good or bad that the cue bends during the stroke, is a delicate question. If the cue's bending is negligible (for example, like a cue from the company «Cuetec» for the Russian Billiards), then all these 200 kg act on the cue ball, trying to torque it over the moment arm, equal to the offset of the center of pressure relative to the center of the cue ball, i.e. 10-12 mm, as in our case. If the cue bends, then at the beginning of the cue hitting the ball, a portion of the impact energy is «pumped» into the potential energy of the bent cue, and then the cue «shoots», while the elastic force of the bent cue is directed almost tangentially to the ball. That is, the straightening cue tries to torque the ball through the maximum possible moment arm, equal to the ball radius. Now, a logical question may arise: how big is the addition to the angular velocity from the straightening cue, because during the stroke the cue bends by several millimeters? Indeed, if you try to bend the cue by this amount with your hands, holding it by the butt and by the tip end of the shaft, the bending force will be tens of grams. This is nothing compared to those 200 kg. Nevertheless, it is important to understand that when you bend the cue with your hands, it is a static load, during the impact (dynamic load) the cue will bend in a completely different way. Within a very short duration of impact (1-2 ms), the force will not just to bend the cue, but move the mass of the cue, supplying it extra speed. Since the impact duration is very short, even a slightest movement of the entire mass of the cue will cause considerable acceleration, that is, great forces are needed to overcome the inertia of the cue. As everything follows the path of least resistance in the nature, it is more plausible that only cue's head (a few centimeters, which weigh, at best, several tens of grams) will bend, rather than the entire cue. And for such a bend, the elastic forces are already an order of magnitude, or even several orders of magnitude greater than if the entire cue were bent. Since the curved part of the cue weighs relatively little, it straightens up quickly enough, additionally torquing the ball. It turns out that in some cases the transverse deformation of the cue is advantageous, which means it can be artificially stimulated. One way to «pump» more energy into the bending deformation is to move the pressure point to the outer edge of the tip, for example, to make (compress) the tip so that its edges are stiffer than the middle. Another way is demonstrated by snooker cues of some top players: their tip has a pronounced mushroom shape, and sometimes this shape is man-made. This shape, as well as sealing the edges of the tip, allows you to move the pressure point away from the cue axis, that is, to create a greater bending moment at the end of the shaft. This idea is also successfully used by Vitaly Arkhipov on his cues. By the way, in my opinion, the presence of sleeves, ferrules at the tip end of the shaft, in this case does not contribute to the «correct» shaft bending.

In general, as usual, there are mutually exclusive factors. A rigid tip in the center is good, but a rigid one at the edges can also be useful under certain circumstances. It is necessary to look for an optimum for each specific cue.