Setting The Scene

On February 12th, I left for work between 7:45 and 8:00am. As usual, I was riding my 33 year old Mercian 12 speed commuter bike. The temperature according to weather records showed a low of 26F overnight. I don't recall being cold on the commute, and I wasn't wearing my arm warmers under my yellow cycling jacket. I was wearing tights and winter gloves, but no head liner under my helmet. Based on my wardrobe, temperature was not an issue for me at departure as I was not dressed for freezing temperatures. I don't recall any moisture in the air, and I don't recall the sky conditions, but I was using my generator light system for safety only, not for illumination purpose.

While heading west on Springettsbury on the block just before George St, I crashed. I don't recall the crash, and I only have very limited memory of being on Springettsbury at all (I was on Springettsbury for two blocks prior to the crash block).

Someone called 911, and a policeman and ambulance arrived. Fortunately for me, a trauma doctor (Dr Najarian) who lived nearby was just leaving for work and supervised my care. He realized I had a severe head injury and became my supervising doctor at the hospital. Turns out that on my left side, I had a fractured skull with internal bleeding (otherwise known as an epidural hematoma), a cracked cheek bone, a broken clavicle, and three broken ribs. I also had one cracked vertebrae in my neck. I required surgery to fix the internal bleeding on my brain which required removing a portion of my skull and the use of two metal plates to reattach the bone to my skull (otherwise known as a craniotomy). I have a very cool (and long) scar on my head. I also had significant bruising of my left elbow and especially my left leg. The left leg bruise was a solid bruise of the outside surface of my thigh. It started just above my knee and extended to include my hip. Oddly, I also had right side injuries. Both knees had abrasions to the right side of the kneecap. The right leg abrasion was significantly worse than the left leg (ex, it took well over a month for the scab to fall off my right knee).

According to the police, there was only one witness, someone out walking their dog who indicated that I was sprinting for the George St traffic light and that no cars were involved. The witness's name was not recorded, so no followup questions are possible. The wife of a friend who lives across the street from the crash came out while the EMTs were working on me. She confirmed that my body (which they would not have moved because of my head injury) was on the street, not the sidewalk. Interestingly, while Springettsbury is a wide street with room

for parking, I wasn't even near the edge of the street, but actually partly out in the active lane. There were no parked cars near where my body lay. It is clear that I went straight down to the road.

My bike was relatively unscathed. While the policemen reported that I was still clipped to my pedals and despite crashing on my left side, my bike had a right brake hood twisted inboard 30-45 degrees, and the rubber hood had abrasions and one tear. This damage is not immediately intuitive, and frankly bothered me extensively until the answer was found. More understandably, my left brake hood was bent inboard 5-10 degrees and the brake lever has abrasions near its top. My leather saddle had a small shallow scrape on its left side near the rear of the saddle.



Note right hand brake twisted with impact damage

The Theories

There have been many rational suggestions. The lack of extensive bike damage and witness description eliminates a car collision. At first given the extreme damage to my left side, the primary explanation involved my hitting the road then sliding into something vertical such as a curb (causing the excessive left side damage) and flipping over onto the sidewalk causing the right side knee damage, but the location of my body with the paramedics pretty well eliminates that.

Being February and the overnight low being below freezing, a lot of people suggested black ice which I rather immediately rejected. I rejected it because over the years, I have often ridden on black ice. In winter, I ride with studded snow tires. These tires have allowed me to climb icy hills that regular cars have difficulty ascending. The studs aren't perfect, but every time I've had slippage, the studs have slowed down the lateral slide, either so that I could re-establish balance or really slow down the actual crash. I've only actually crashed once, and I had no serious injury, as it happened in slow motion.

Of course the key is knowing you are on black ice, and generally if conditions hint at black ice then my riding style becomes very conservative. Since the accident occurred in the morning, I was riding to work which means a downhill journey of several hundred vertical feet. Generally, once I get off the hill and into town, road conditions improve. I don't remember the accident at all, but I do recall the early part of the ride, and I don't recall any road issues. Thus, it is quite likely that when I turned onto Springettsbury Rd, I had decided that I could ride normally.

I turn onto Springettsbury three blocks from the light at George St, and while in the past the light cycle has been generous to the Springettsbury traffic, lately it has not been. Which means that if you aren't at the light or very close when it turns green, then it is highly unlikely you will get across. And since in the winter (when there are no tree leaves) I have a clear vision of the light from three blocks away, this means I have three blocks to vary my speed so that I arrive at the light when it turns green. Furthermore, there are sensors in the street on either side of George St and while my bike can trip the sensor on the west side of the light (ie, when I ride home from the office), I have had no luck tripping the east side sensor (ie, when riding to the office in the morning). This means that I pay attention to any cars coming toward the light on the other side (ie, coming from the college) because I know they will trip the sensor and thus turn the light green. My last memory from that morning is being roughly a block and a half away and seeing two cars roughly a block and a half away from the light on the

other side. We both had a stop sign to pass through, and I needed to roughly match the cars' speed so that when they tripped the light from the other side, I would be close enough to make it through the green light.

<u>The Crash</u>

So I don't remember anything that happened, but I am confident that I felt the need to match the speed of the cars approaching the light on the other side, and I wasn't concerned about road conditions. Finally, the lone witness said I was sprinting for the light. So, I think I was sprinting for the light.

In general, while a nice (albeit 33 years old) machine, my commuter bike is not configured for racing, and with the snow tires and the drag from my lighting generator it is definitely not a speed demon. I am a heavy guy and sprinting means using my mass to help push each pedal down. This means that while the bike will travel in a straight line, the bike will lean right and left to counteract my weight and leg thrust. Since the tread of my snow tires are very flat 'V' shaped with essentially vertical sidewalls, not round like a normal tire, and the studs are attached at the outboard edges of the 'V', the bike leaning during sprinting will lift one set of studs off the road. This will make the tire slide laterally much quicker, and worse still when the tire slides laterally enough to be beyond the edge of the 'V' of the tread, vertical sidewalls mean the support of the tire disappears. Unlike a normal round tire, there is a very real tipping point.



Note flat V of profile and alternating studs



Note flat side wall

It appears I hit a patch of black ice while leaning during sprinting. Since the temperature was above freezing it is quite likely any evidence of that black ice was gone when authorities arrived. It is possible that it was a regular sheet of ice (spilled water, a discarded soda, etc), but I am not sure it would have melted in time and might have been noticed. Regardless, my lateral coefficient of friction was severely reduced by my 50% reduction in studs which resulted in a rapid lateral slide. And in reality, the alternate spacing of the studs on each side means that the 50% reduction is actually an average. The reduction could be from three studs to one studs (66% reduction - very bad) or from three studs to two studs (33% reduction).

So I am confident that my leaning eliminated enough studs gripping the road that

a significant lateral slide occurred toward my right. There remains two primary questions. How did the damage to the right side of my knees and to the right side of my bike (the right brake hood twisted inboard) occur? And how did the subsequent crash cause so much physical damage to me?

My wife Gina had the very unique idea that perhaps the handlebars twisted a full 180 degrees during the drop to the street. Given my past slides on black ice and how slow the lateral slide occurs, I couldn't see a situation where I could have my balance fail so completely, and the handlebars would rotate 180 degrees; however, once I realized just how much friction I could have lost and the handlebar pressures during a sprint, it is not out of the realm of possibility. Had I been sitting when the lateral shift to the right occurred, I would have turned the handlebars right to remain balanced (just as when a car slides), but while out of the saddle during a sprint, it is totally possible that my only hope was to turn the handlebars to the left as well as tilt my body to the left (to essentially do a 90+ deg sliding turn to the left), but instead I went down in a heap. See [Additional Data: 8/26/2013] below (top page 15) for a current discussion of the timing of handlebar rotation.

Interestingly, since I was found still clipped in, I was able to easily recreate my position, and voila with the handlebars turned to the left as far as they can go (not quite a full 180 degrees because they run into the top tube of my frame), and with my right pedal up and my left pedal down, my right knee wound exactly matches the left end tube of my handlebars which stuck through to the right side of my frame. My right knee wound is nasty because it is the blunt end of my handlebar which scraped across the right side of my right kneecap. Similarly, the left brake hood perfectly aligns with the right side of my left kneecap. The brake hood is rubber encased, so the scraping across my knee was less damaging. The twist of the left brake hood 5-10 degrees and rough scraping of the metal brake lever was done by a brief contact with the road as the handlebars rotated through. The twist of the right brake hood 30-45 degrees was caused by the final impact with the ground. Everything matches up, so it is clear that my handlebars twisted fully to the left during the crash.



Note impact of knees with left handlebar and twist of right brake hood

So how was so much of my body damaged? Well it is pretty obvious that the crash happened quickly (ex, I was still clipped in), but can an estimate of impact speed be calculated? Well, if some assumptions are made, then yes a simple analysis can be performed.

Assumption #1

The movement during the crash is assumed to be a lateral slide to the right of the bottom of my bike which extends far enough for balance to be lost and a rotation to the left to occur. In addition, the center of gravity of body and bike drops to the road accelerating due to gravity. This is likely quite a simplification of what actually happened. First of all, I initially thought that as the bike slid out that me and the bike were a rigid body and just dropped vertically, but initially as I lost balance and tried to recover by turning the handlebars to the left - that is not likely the case. The middle sketch below shows as the bike slides further to the right and the handlebars start to rotate to the left (not drawn), my upper body leans more to the left (or really down) and is the primary impetus of the

rotation, although it isn't a true body rotation in that it is highly unlikely the other end (ie, the tires) lift off the ground. Given the extensive upper body damage, I also assume that my head hits at the same time as the rest of my body.



Assumption #2

To calculate the tangential velocity of my head as it rotates, as well as the total time for the center of gravity of body and bike to drop due to gravity to the road, the center of gravity of the combined body and bike needs to be calculated. Very rough measurements of my center of gravity in riding position and of the bike were made. I assumed my riding position was 70 degrees from vertical and I had one foot down and one up.

<u>Analysis</u>

First step is to determine the center of gravity of the body and bike. This was done as follows:



Wb – weight of bike 35 lbs
Xb – center of gravity of bike – 18 in
Wj – weight of me – 235 lbs
Xj – center of gravity of me – 38 in
Wt – weight of me and bike – 270 lbs
Xt – center of gravity of me and bike (to be calculated)

Need to convert the center of gravity measurement of me to be parallel to the bike since I am leaned over 70 degrees. My foot is 5" above the ground (pedal at bottom of stroke)

Xj = 5 in + (38 in * Sin(70)) Xj = 40.7in Wb*Xt + Wj*Xj = Wt*Xt 35(18) + 235(40.7) = 270*Xt 10,194.5 = 270*Xt Xt = 37.8 in

Now we need to determine how long it takes for the center of gravity to fall to the street due to the acceleration of gravity.

 $X = 1/2(A)(T)^2$

Where X is Xt (actually slightly less since I needed to tip over far enough for the tire edge to be exceeded) and A is g (acceleration due to gravity, 32.2 ft/sec²), solve for T.

 $Xt = 1/2(g)(T)^2$ $T^2 = 2(Xt)/g$ T = sqrt(2(Xt)/g)

Need to convert Xt to feet, so

Xt = 37.8 in (1 ft/12 in) Xt = 3.2 ft

T = sqrt(2(3.2)/32.2)T = 0.45 seconds

Not a lot of time to react, so no wonder I never unclipped nor corrected for the lateral movement.

Next is to calculate how fast my center of gravity hit the street.

V = AT

Where A is g (acceleration due to gravity, 32.2 ft/sec^2):

V = 32.2 ft/sec^2 * (0.45 sec) V = 14.5 ft/sec

Next is to calculate the impact speed of my head since it is rotating around my center of gravity. First, we need to calculate the rotation velocity, then convert to tangential velocity. Since we have assumed that my body and bike were horizontal at impact, and ignoring that I was slightly leaning initially, the rotation is 90 degrees or $\P/2$ (1.57) radians.

Rotation (1.57 radians) = w T where

w = rotation velocity in radians/second

Solving for w.

w = Rotation/T w = 1.57 radions / 0.45 sec w = 3.49 rad/sec

Convert to tangential velocity at the tip of my head.

Vt = wR

Where R is the length from the center of gravity to the tip of my head. First, we need to calculate the height of my head above the street.

H = 5 in + (70 in * Sin(70))) H = 70.8 in

Then subtract the height of the center of gravity.

R = 70.8 in - 37.8 in

R = 33 in

Convert to feet.

R = 33 in (1 ft/12 in) R = 2.8 ft

Vt = 3.49 rad/sec (2.8 ft) Vt = 9.8 ft/s

So, at my head the total vertical velocity into the street is.

V = 14.5 ft/s + 9.8 ft/s V = 24.3 ft/s

Converting to MPH.

V = 24.3 ft/s (3600 s/hr) (mi/5,280 ft) V = 16.6 MPH

[Additional Data: 11/26/2013]

So, I realize that trying to appreciate the impact of a body part with an immoveable surface at 16.6 MPH is difficult to grasp, so given that the kinematics of my analysis involve the vertical drop of my body as well as a rotation (essentially vertical to horizontal), I thought it might be useful to determine how high my head needs to be dropped vertically to reach that same speed of 16.6 MPH.

V = ATT = V/A

A second equation of movement: Y = $\frac{1}{2}$ AT^2

Where Y = distance moved A is g (acceleration due to gravity, 32.2 ft/sec^2):

Substitute first equation into second equation: $Y = \frac{1}{2} A(V/A)^2$ $Y = \frac{1}{2} V^2/A = V^2/2A$

Above, V = 16.6 MPH = 24.3 ft/s

 $Y = 24.3^{2}/(2 * 32.2)$

Y = 9.2 ft

Ooh, that is more graphic. Take your head off your body and hold it 9.2 feet from the pavement (you may need to use a stool to get that high), then let go...

What about my shoulder? Lots of collarbone damage, so how high would an equivalent vertical drop be? We previously calculated that the top of my head was rotating around my center of gravity 2.8 ft away. My shoulder which is one foot lower would be rotating 1.8 ft from my center of gravity, so total velocity of my shoulder is:

Vt = 3.49 rad/sec (1.8 ft) Vt = 6.3 ft/s

So, at my shoulder the total vertical velocity into the street is.

V = 14.5 ft/s + 6.3 ft/s V = 20.8 ft/s

Converting to MPH.

V = 20.8 ft/s (3600 s/hr) (mi/5,280 ft) V = 14.2 MPH

 $Y = 20.8^2/(2 * 32.2)$

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Y = 6.7 \, ft
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Still a pretty long way to drop and no wonder bones broke... [End Additional Data: 11/16/2013]

So, given the vertical velocity of my head was 16.6 MPH I also had a horizontal velocity. Problem is I don't know what that was, but given that I was sprinting, I can safely say it wasn't much less than 16.6 MPH. However, it may not have been much more. I have already noted that I was riding on snow tires which are as anti-racing as a tire can be, and I had the added drag of a headlight/taillight generator. Furthermore, I crashed about 30 vds past a stop sign, so I didn't have a lot of space in which to accelerate, and finally my commutes to work are not intended to be workouts, so I don't think I was faster than 25 MPH, and could have been as low as 15 MPH. The problem is there is no data. High speed crashes tend to cause severe road rash (ie, skin abrasions), and I had exactly no road rash. Granted I was wearing tights and jacket which were destroyed and may have given their lives to save my skin, but I am doubtful as the one time I fell with tights, they didn't save my leg from road rash. So either my speed was significantly lower than a sprinting speed, road surface had widespread black ice which limited the road rash potential, or something else caused me to horizontally decelerate quickly. We'll never know. My bike was found in a big sprinting gear, so it seems likely I was going fast, but we'll never know. One possibility is the geometry of the crash with my handlebars spinning around causing the front wheel (especially) and right brake hood to essentially act as a good drag brake. There is damage to the right brake hood, and the wheel is slightly out of true, but

if there were more brake hood and wheel damage I'd feel better about this scenario.

[Additional Data: 8/26/2013] I was given medical permission to begin cycling in early August, and while I initially started riding my road bike, I eventually got around to correcting the minor damage to my commuting bike. Repositioning the brake levers and checking for metal damage on the levers and handlebar was easy. Turns out I completely underestimated the front wheel rim damage. Yes, there is a 1/8 diameter section that is out of true, but it finally occurred to me that it is out of true toward the right side of the bike which means the wheel had not rotated 180 degrees when the highest force occurred (ie, the impact). Furthermore, when I tried to true the rim back, I immediately broke a spoke without putting much torque on the spoke wrench. It clearly was severely stressed during the impact. The rotation of the handlebars had to happen guickly because they had to impact my knees with enough force to cause my nasty knee wounds. I had originally assumed that the vertical velocity of my body against the already turned handlebar caused the knee wounds, but I now believe that my weight falling against the frame (and thus front wheel) while the wheel was still pointing forward caused the rim deflection; therefore, it had to be the whipping of the wheel due to friction of the tire with the road (essentially stubbing) as it rotated 180 degrees into my knees that caused the knee damage. This with zero road rash makes me believe I didn't slide much and my horizontal deceleration wasn't trivial. I still can't put a number on it, and while it wasn't trivial, my horizontal deceleration will still likely pale next to my vertical deceleration. [End Additional Data: 8/16/2013]

In terms of calculating a complete velocity vector I will run three calculations using my horizontal speed at 15 MPH, 20 MPH and 25 MPH, and I will show the angle of the vector to indicate just how much of the horizontal speed can be thought of as a glancing blow. However, it is important to understand that the real question is unanswerable, how quickly did I decelerate horizontally which is really how physical damage occurs (road rash most commonly). Vertically, I decelerated instantaneously. 16.6 MPH may seem slow, but understand I went from 16.6 to zero in an instant. I don't know how that transition occurred horizontally.

The math to calculate the total vector is simple, and the calculated angle of the vector will be from the road.

 $V = sqrt(Vv ^2 + Vh^2)$

angle = tan-1(Vv / Vh)

Vv (vertical vel)	Vh (horiz vel)	V (total vel)	Angle from road
16.6 MPH	15 MPH	22.4 MPH	47.9 Deg
16.6 MPH	20 MPH	25.6 MPH	39.7 Deg
16.6 MPH	25 MPH	30.0 MPH	30.0 Deg

My Helmet, the Hero

Fortunately, I was wearing my helmet. A bicycle helmet's goal is to prevent a hard object from ripping into the scull (hence the hard plastic shell) and to slow the deceleration and spread the impact load (hence the foam core). From the attached photos you will see that the foam on the left rim of my helmet was compressed. It was compressed approximately 50% over approximately 4inches of the rim and 1 inch into the helmet. As you can see, my head impacted on the very edge of the helmet which limited its ability to spread the load, but it was apparently quite good at slowing my deceleration. Impacting the edge of the helmet also explains my cracked cheek bone. My helmet also suffered a total of 10 cracks through various foam ribs located in the front half of the helmet.



Left side of helmet, note foam compression at top



Right side of helmet, note no compression

According to information from <u>www.helmets.org</u>, a helmet will improve the deceleration of a head 500%. A bare head slamming into an immoveable object will decelerate in 0.001 seconds, and a head with a helmet will decelerate in 0.006 seconds – still really, really abrupt, but it significantly reduces physical damage. Generally speaking, a deceleration above 300g will cause permanent brain injury. Note: that if you are sitting in a chair in a stationary room (ie, not a car, etc) then you are subjected to the steady gravitational pull of 1g.

For both bare and helmeted conditions the g loads I experienced for the range of velocities (V) (listed in the table above) are listed in the table below.

V = A t

Where V is the velocity of my head at impact (converted to ft/sec), A is the deceleration (converted to multiples of g, 32.2 ft/s^2) and t is the time of the deceleration (t = 0.001 sec for bare head, and t = 0.006 sec for a helmeted head). Solving for A.

A = V / t

For V = 22 MPH

V = 22 MPH (5,280 ft / 3,600 sec) V = 32.3 ft/sec

For a bare head.

t = 0.001 sec A = 32.3 ft/sec / 0.001 sec A = 32,300 ft/sec^2 g = 32.2 ft/sec^2, so A expressed as a multiple of g is.

A = 32,300 ft sec^2 / 32.2 ft/sec^2 A = 1000g

For a helmeted head. t = 0.006 sec A = 32.3 ft/sec / 0.006 sec A = 5,383 ft/sec^2 A = 5,383 ft sec^2 / 32.2 ft/sec^2 A = 167g

Velocity (V)	Bare Head g Load	Helmeted Head g Load
22 MPH	1,000g	167g
26 MPH	1,180g	197g
30 MPH	1,362g	227g

Even if you ignore the horizontal component of my velocity and use only my 16.6 MPH vertical velocity, the bare head g load is 743g, and helmeted g load is 124g. In all cases, the helmeted g loads are below the 300g limit for permanent brain injury and the bare headed g loads are well in excess. Fatally in excess? Definitely a reason to wear a helmet, and why I am contemplating a special permanent display for my helmet the hero.

Summary

The bottom line is there are some unknowns as to the mechanics of my fall to the ground, so assumptions are made, but it is very clear that my bike slipped to the right violently while I was sprinting to be in position to cross George St when the light turned green. I was unable to recover from the slide and the left side of my body crashed into the road. The damage is really hard to believe, but it is obvious that without a helmet I would not be writing this document.

So I only have to look in a mirror to see who was responsible for my accident, and the incredible support I have received from family, friends and colleagues has made all the difference in the quickness of my recovery. I can't begin to list everyone, and other than a very broad genuine thank you, I am not sure how to repay everyone for their generosity. And I can't say enough about the quality of care I received at Wellspan – when minutes counted as I bled internally, they completely hit a home run caring for me. And the rehabilitation staff helped me become a functioning person again. I'll never forget what they did for me.

Also, Dr Roser and Bev Lentz at Vision Therapy Associates have been absolutely instrumental in getting my eyes working productively as a team again, so I'll also never forget their contribution to my recovery. Double vision is no fun!

Please excuse grammatical errors, but if I have made a math or physics error beyond my stated assumptions, then please do let me know.

The following appendix contains images of my wounds, so if you don't like to see such things please don't and instead jump to the last page which is a current, and very happy, picture of me.

Appendix A The Aftermath



Day 4



Day 4



Nice pic of the two circular plates used to hold me together



Broken collarbone and three ribs





Day 6 Nice bruise, note swelling around knee



Happy, Week Nine