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Time: Critical Factors in Injury Risk, Part I

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You may have noticed previous articles on the subject of auto crash reconstruction (ACR) in this column. I’ve even written a five-part series about it. Although the math and physics may bring bad memories back to some, it is really not as complex as it might appear. Many DCs who view their roles as generalists are understandably not inclined to venture into the issues of ACR to any great depth. However, anyone who might have occasion to treat a patient injured in a motor vehicle crash (MVC) should at least understand the rudiments of crash dynamics, as a means of gauging the energy transfer to the occupants in that crash. From this, of course, clues to likely areas and severities of injury can be gleaned, which should assist in the correct diagnosis and work-up of the patient. It should also help in writing a credible narrative report, should one be requested by the patient’s lawyer or an insurance company.

To keep things simple, I’ll introduce a single, simple equation here - perhaps the most important one in terms of the fundamental issue in occupant injury risk:

$$a = \Delta v / \Delta t = 7.35$$

In this equation, a is acceleration in feet per second squared (fps^2); Δv is the overall change in velocity of the crash in feet per second (fps); and Δt is the overall duration of the crash in seconds. That’s it; pretty simple. And if you want to convert mph into fps, you simply multiply mph by 1.47 (and divide fps by that number to convert back). To get acceleration in the more familiar gravitational units (g), simply divide the fps^2 value by 32.2.

The only caveat with this arithmetic is that the equation gives you *average* acceleration. In the context of injury causation or risk assessment, however, what we really want to know is *peak* acceleration, which is almost always higher. At this point in my talks, I usually invoke the popular statistics joke about the statistician who drowned fording a stream with an average depth of three feet (which generally "falls flat," though I tell it anyway). The point is simply this: What the statistician fording the stream really needed to know was the maximum depth of the stream. Likewise, if our goal is risk assessment, we really only care about peak (maximum) acceleration.

Granted - math humor is pretty dry-so we'll keep things simple here. Why is time such a critical factor? Its position in the denominator tells the story. I like to use a couple of extreme examples: First, the space shuttle. It takes roughly one hour (3,600 seconds) to get up into its final orbit. At that point its velocity is approximately a brisk 18,000 mph - or about 26,460 fps. If we put these numbers into our equation we get:

$a = 26{,}460/3600 = 7.35$

If we divide this figure by 32.2, we get a rather trivial-sounding 0.2 g. According to NASA, astronauts at take-off experience up to 8 g - about 40 times greater than this paltry 0.2 g value. This gives us an example of how average acceleration and peak acceleration can vary considerably. And, as it turns out, it's one of the common tricks used by defense experts to attempt to trivialize a particular crash. The defense will report the average acceleration rather than the peak acceleration - a little mathematical slight-of-hand that is only partially untrue. The calculation is correct, while the unstated implication that this number applies to the occupant, tacit as it usually is, is false. Moreover, they often report the average acceleration of the vehicle rather than that of the occupant. The occupant's resultant head acceleration is nearly always higher than that of the vehicle, sometimes by a factor of two times or more.

Let's now take a more down-to-earth example of a low-speed rear-impact crash (LOSRIC). Suppose we take a common crash speed change of five mph (7.35 fps). The typical duration of the occupant kinematic portion is about 0.12 seconds and, since it's the occupant's acceleration - and not the vehicle's - in which we're interested, we'll use this figure as the denominator. Again, note: The overall crash duration, including the vehicle response may be 0.40 seconds or longer, depending on how you set up the crash and how you define and measure its duration, but using such a figure will underestimate the occupant's acceleration grossly. Not surprisingly, it is yet another example of the nimble *legerdemain* used in defense circles to marginalize real world crashes. In any case, we have:

$a = 7.35/0.12 = 61.25$

Again, dividing by 32.2 gives us the more familiar term of 1.9 g. This may intuitively sound like another pretty trivial acceleration. In fact, it is. After all, we are all under the influence of 1 g just walking around. Yet published data from human subject crash tests, including those conducted at my institute, seems to indicate that a 5 mph ∆ v is the threshold for whiplash injury, and some more recent studies have suggested this threshold may be as low as 2.5 mph. And, certainly, for persons with additional risk factors (e.g., advanced age or spondylosis, prior injury, pre-existing neck pain, etc.), while the actual risk threshold can never be firmly established, the threshold for injury is almost certainly lower than it is for healthy volunteers.

The explanation lies again in the difference between average acceleration-which is what we just calculated-and peak acceleration. To know what the instantaneous acceleration is at any particular time, and thus get an idea of what the peak acceleration might be, we have to develop derivatives of velocity and time using calculus. Alternatively, it is equally instructive to simply look at the findings from the several human subject crash tests that have been conducted to appreciate the relative accelerations between car and occupant. Typically, for a rear impact crash in the 5-mph speed change range, the head resultant acceleration for larger subjects will be in the neighborhood of 7g, and for smaller subjects about 12g. Naturally, other variables, such as the relative masses of the crash partners, occupant position and bracing, are also important.

Understanding this equation also helps us to appreciate another important term: *ride-down.* Clearly, any event that increases the duration of the crash, assuming the speed change is held constant, also reduces the acceleration and can be thought of as ride-down. In MVC there are lots of examples of ride-down. When sheet metal crumples, for example, the crash duration is increased. So, despite a more formidable or dramatic appearance of the crash product, the relative loads to the occupant are actually reduced. In contrast, in low-speed crashes, in which no crumpling of metal occurs, paradoxically greater relative loads are passed on to the car’s occupants because the crash is actually stiffer - and the duration is less. When a seat back bends and deforms under the inertia of its occupant in a crash, precious ride-down is also gained by the occupant. The water-filled containers seen on some highway sections are designed to rupture when struck by a speeding, out-of-control vehicle. This action also provides ride-down. The padded interior parts of the car’s dashboard and knee bolster provides ride-down, as do even the metallic headliner frames. And there are many other types of ride-down. Even an airbag functions largely by providing critical ride-down during a crash, as do the seat belt and shoulder harness.

In the future, when you contemplate what type of forces your patient might have been exposed to, or whether a certain crash might or might not have resulted in injury, pay special attention to the physical crash factors which have a bearing on this important phenomenon called ride-down. As we’ll see in Part II of this article, the *distance* allowed for deceleration - which is also related to the duration, of course - is an equally important factor. We'll look at yet another very straightforward equation that you'll be able to use to estimate the contribution to injury reduction offered by distance.

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