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Forensic Engineering Analysis: Biomechanics is an Engineering Discipline

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Abstract

Forensic engineers with expertise in the field of biomechanics are frequently retained to conduct a biomechanical analysis of some injury-related incident. This may involve the areas of injury event reconstruction, what forces may have been involved, how the person responded to these forces, and whether injury mechanisms consistent with the claimed injuries were (or were not) established during the incident. It is the view of some engineering biomechanics experts that the presentation of injury mechanism-related opinions is based on biomechanics (a subject of engineering) and is not intended to serve as an opinion regarding injury causation (i.e., was the claimant injured as a result of the described incident). Attorneys have challenged the ability of forensic engineering biomechanics experts to offer injury mechanism-related opinions (and often the other associated areas described above) based on a theory that "biomechanics" is not a subject of engineering, but rather a subject of medicine, and, in turn, the engineering expert should not be allowed to present such opinions. This paper explores the validity of this claim, focusing on the academic evidence. More specifically, academic programs within the United States in both the areas of engineering and medicine were examined to find evidence of formal classes in the area of biomechanics, dedicated biomechanics research activities, current textbooks and references (focusing on author affiliation), and other academic-related activities.

Keywords

Biomechanics, injury analysis, biomedical engineering, forensic engineering

Introduction

Engineers with expertise in biomedical engineering (with a focus on biomechanics) are often retained by attorneys to provide analysis and render opinions in the area of injury biomechanics. Biomedical engineering is the engineering-based discipline at the interface of engineering mechanics, dynamics, materials, modeling/analysis, and relevant areas of clinical and research medicine. Biomechanics is a major sub-discipline of biomedical engineering that employs these areas to focused problems, such as: the understanding of how the body moves, the forces involved, and how the body responds to forces; mechanical behavior of various tissues such as bone under various loading scenarios (up to injury); orthopedics, including the behavior of joints and associated structures and the design of orthopedic implants; and occupational biomechanics and ergonomics. Injury biomechanics is a focused area of biomechanics that examines how the body or tissues react to load scenarios that are associated with injury. Injury biomechanics may be used to understand how a given injury may or may not have occurred in a given situation. Injury biomechanics is also employed in areas such as automotive design and safety engineering to prevent injuries from occurring.

Figure 1 presents a list of typical areas where a biomechanical analysis might be conducted. Typically, an individual makes an injury claim as the result of a specific event, such as a vehicular collision, slip and fall, falling object, etc. Forensic engineering experts are retained to provide opinions on what types of forces might have been experienced by the claimant, what types of injury mechanisms might have been established, etc. Often, a separate engineering expert is retained to formally reconstruct the injury-related event; however, some engineering experts can evaluate both the reconstruction phase and the biomechanics phase of the analysis. It should be noted that any of the parties involved in the litigation process can retain such expertise; often biomechanics experts are retained by both plaintiffs and defendants in civil matters. From an ethical viewpoint, a given biomechanics expert's opinion should be independent of which party retained the expert.

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Acceleration/deceleration injuries
- Vehicular collisions
- Single vehicle incidents
- Slip/trip-and-falls
- Elevator incidents
- Head/neck (or other body areas) acceleration/deceleration

Blunt trauma
- Vehicular collisions
- Pedestrian-vehicle incidents
- Falling objects
- Fall from height
- Slip/trip-and-falls
- Sports/recreation incidents
- Battery incidents

Other areas
- Seat belt issues
- Air bag issues
- Helmet issues
- Repetitive motions
- Medical malpractice
- Product liability

Figure 1
Examples of injury-related events where a biomechanics opinion may be presented.

During the litigation process, many attorneys will try to challenge the qualifications, methodology, and opinions of biomechanics experts, often basing their challenge on rules of evidence, such as the *Frye* or *Daubert* standards. **Figure 2** presents examples of the types of statements opposing counsel may weave into a legal argument in an attempt to exclude/limit/strike a biomechanics expert. This paper focuses on one specific type of challenge: that biomechanics (in general) and often injury biomechanics (specifically) are disciplines of medicine and not engineering. Therefore, only an MD, DO (Doctor of Osteopathic Medicine), or occasionally a DC (Doctor of Chiropractic) can offer any such opinions. Stated alternately, it is asserted that an engineer in a medically related engineering discipline (e.g., biomedical engineering) is not qualified to offer biomechanics-related analysis and opinions because biomechanics is not recognized as an engineering discipline but rather a discipline of medical science. It should be noted that "medical opinions" do include: was the claimant injured; was the diagnosis appropriate; was the treatment appropriate (including any physical or rehabilitation therapy, drug prescription, surgical interventions, etc.), was there permanent impairment, future health possible trajectories, etc. Engineering experts do not normally address such areas, recognizing them as "medical opinions." However, the author contends that the argument — engineers cannot offer biomechanics opinions because "biomechanics" is a medical subject (not an engineering one) — is invalid.

- Dr. X is rendering medical causation opinions. Since Dr. X is not an MD, he/she is not qualified to render such opinions.
- Opinions related to biomechanical mechanism of injury can only be offered by an MD, since mechanisms of injury is a subject of medicine and not of engineering.
- Dr. X cannot offer opinions related to biomechanics since he/she did not examine or otherwise treat the patient.
- Dr. X is not qualified to read medical records that document the claimed injuries; therefore, his/her opinions related to biomechanics should not be allowed.
- Dr. X cannot cite any peer-reviewed literature that documents his/her methodology related to his/her biomechanical analysis. Therefore, Dr. X's opinions should not be allowed.
- Dr. X's "methodology" is not generally accepted by his/her scientific community and is, in fact, based on "junk science." As such, it does not rise to the standards of either *Frye* or *Daubert*.
- Dr. X cannot cite a peer-reviewed article where a person of the plaintiff's age/height/weight and general physical condition was included as a subject in any studies. Therefore, Dr. X's "biomechanical" opinions are pure speculation and should not be allowed.
- Dr. X was not a witness to the collision, so he/she cannot say anything that is reliable regarding how the plaintiff moved in regard to the rear-end impact.
- Dr. X's references to Activities of Daily Living to supposedly assist the jury in understanding what 1 *g*, 2 *g*, 3 *g*, etc., mean is just a back-door way of arguing medical causation and therefore should not be allowed.
- Dr. X failed to agree with the plaintiff's treaters who clearly document that the plaintiff's injuries were caused by this accident. Obviously, the plaintiff's treaters are in the best position to opine that the plaintiff's injuries are a direct result of this accident.

Figure 2
Examples of phrases cited in various motions to exclude/limit/strike biomechanics experts.

It is important to note that there is a difference between "medical causation" and "biomechanical causation." Medical causation refers to whether a specific event did or did not cause a specific claimed injury from a clinical point of view. This may be especially problematic regarding soft tissue injuries. Often, the medical causation claim is based on the patient's self-reported history (for example, "I was fine before the event") or by a diagnosis of exclusion. As such, this is usually subjective information and not particularly "objective-scientific." The claim may also be based on the treating physician's clinical knowledge of the nature of the injury in question (for example, many subjects in rear-end collisions experience whiplash). Objective findings may indicate that an injury event may have occurred in the past, but when the event actually occurred may be difficult or impossible to determine. Indeed, physicians may often commit the *post hoc ergo propter hoc* logical fallacy (i.e., where one concludes that one event followed by another is sufficient evidence to conclude a causal relationship between the two). The American Medical Association guidelines[1] regarding injury causation present the methodology that should be followed in determining causation, and it states that causation opinions should not be based solely on the subjective history as provided by the patient. Complicating the issue, physicians may be providing opinions in cases where the treatment and diagnostics were performed under a letter of protection or similar agreement; the physician may have a vested interest in the outcome of the case. In contrast, "biomechanical causation" indicates whether the temporal events relative to the claimed injury, associated movements/forces, and potential mechanisms of injury are consistent with the claimed injury. Medical causation is based more on clinical knowledge, and biomechanical causation is based on engineering mechanics, physics, etc.

A related problem regarding who is qualified to render biomechanics opinions is often encountered in litigation where a physician renders what are clearly biomechanical opinions. For example, the physician may opine that forces were insufficient to cause the injury of interest or simply that the explanation of how the injury occurred is not tenable. This is a significant problem in the area of physical child abuse where pediatric physicians offer "biomechanical" opinions in areas such as short falls and acceleration-deceleration injuries ("shaken baby syndrome"). Physicians who also hold engineering degrees may be qualified to render biomechanical opinions. However, most physicians have undergraduate degrees in the life sciences with minimal physics. Therefore, such physicians' ability to offer opinions regarding forces, loading behavior, mechanical failure, etc., is often justifiably suspect.

Evidence to support the claim that biomechanics is, in fact, grounded in engineering will be presented from the following sources: 1) an analysis of engineering academic programs in this country wherein biomechanics and related subjects are taught; 2) an analysis of "injury biomechanics" as curricula in the United States medical academic programs; 3) an analysis of established research entities in the area of injury biomechanics; 4) an analysis of the literature in injury biomechanics (coauthor status, affiliations, etc.) and subject areas addressed and methodologies; and 5) other relevant information. The results of this investigation will clearly show that biomechanics and the focus area of injury biomechanics are well grounded in engineering and, in fact, are not addressed in medical school curricula.

Analysis

The Accreditation Board for Engineering and Technology (ABET) website[2]*, The Online Guide to Engineering School*[3], and other resources such as the Biomedical Engineering Society (BMES) website[4] were included to identify engineering programs in biomedical engineering, bioengineering, or other disciplines that might include biomechanics (for example, mechanical engineering). The Association of American Medical Colleges (AAMC) website[5] was consulted to identify Doctor of Medicine (MD) programs. The American Association of Colleges of Osteopathic Medicine (AACOM) website[6] was consulted to identify Doctor of Osteopathic Medicine (DO) programs. The Council on Chiropractic Education (CCE) website[7] was used to identify programs leading to the Doctor of Chiropractic (DC) degree.

For engineering and medical sciences programs, as identified via the above resources, each program was examined for the offering of permanent courses in biomechanics, including general biomechanics and more specialized classes, such as soft tissue biomechanics, orthopedics biomechanics, injury biomechanics, research methods in biomechanics, etc. Classes such as "special topics," "independent study," "directed research," etc., were not considered. In addition, general or survey classes (for example, "Introduction to Biomedical Engineering") were not considered. For the engineering programs, the analysis focused on bioengineering (BioE) and biomedical engineering (BME) programs; when an institution offered one or both of these, the associated mechanical engineering (ME) program was also investigated. Each surveyed program and institution were also probed for a biomechanics-related area being a designated area of emphasis as well as the existence of a defined research group/laboratory/etc.

For textbooks related to biomechanics, the Amazon and Barnes & Noble websites were searched along with a broader Google search. When an in-print text was identified, the author(s), affiliation, and credentials (as available) were noted. In addition, a Google search was conducted to identify research groups, laboratories, institutes, etc., with a focus on biomechanics. The latter search was performed to identify possible research entities that were more broadly defined, possibly spanning several academic units or perhaps not directly affiliated with an academic institution. When possible, the types of individuals associated with the research entity (MD, PhD, discipline, etc.) were noted.

Results

According to the Accreditation Board for Engineering and Technology website, there were 612 institutions in this country with accredited engineering programs (3,002 total departments/programs) as of the 2013-2014 accreditation cycle. Of these programs, there were 167 schools with programs in bioengineering or biomedical engineering, of which there were 92 ABET-accredited BS programs in BioE or BME (as of 2015). It is important to note that ABET only accredits undergraduate engineering programs. Many BioE/BME programs offer only graduate degrees, although there is a growing trend to establish Bachelors BME programs. The Association of American Medical Colleges identifies 145 accredited medical schools in this country; the same programs were identified in the Liaison Committee on Medical Education website. The American Association of Colleges of Osteopathic Medicine identifies 31 accredited colleges of osteopathic medicine in this country (44 teaching locations in 29 states). According to the Council on Chiropractic Education, there are 15 accredited programs (at 18 locations) in this country.

Figure 3 summarizes the results of the survey of accredited academic programs in engineering and the medical sciences. Of the 167 programs surveyed in engineering per the protocol outlined above, 155 (92.8%) included at least one course in biomechanics. More than one biomechanics course was offered at 91 (54.5%) of the 167 programs. Beyond the basic biomechanics courses, many programs offer additional courses such as orthopedic biomechanics (12 programs), soft tissue biomechanics (22 programs), and biomechanics research methods (9 programs). Specific examples of courses beyond a basic biomechanics course include:

- Movement biomechanics, and rehabilitation (Case Western Reserve University)
- Structure, mechanics, and adaptation of bone (Columbia University)
- Musculoskeletal biomechanics 1, 2 (Marquette University)
- Advanced musculoskeletal biomechanics (Columbia University)
- Experimental biomechanics (Drexel University)
- Introduction to orthopedic biomechanics (Johns Hopkins University – Mechanical Engineering)
- Orthopedic biomechanics (several programs)
- Tissue mechanics (Georgia Institute of Technology)
- Biomechanics of the spine (Marquette University)
- Soft tissue biomechanics (Stanford University)
- Fracture mechanics (University of Alabama – Birmingham)
- Ergonomics of occupational injuries (University of Iowa)

Degree offered	Programs Surveyed	Programs offering biomechanics course(s)	Programs where biomechanics is an identified area of emphasis
BME/BioE/ME	167	(at least one) 155 (more than one) 91	138
MD	145	0	0
DO	31	0	0
DC	15	0	0

Figure 3
Summary of the survey of academic programs in engineering and medical sciences.

- Impact biomechanics (Virginia Polytechnic Institute – Mechanical Engineering and Wayne State University)
- Experimental methods in impact biomechanics (Wayne State University)

Wayne State University offers a graduate certificate in injury biomechanics within its BME program. Stanford University offers a B.S. biomechanical engineering program (only such degree program in this country). The University of Texas Mechanical Engineering department offers a “biomechanical engineering” program (the awarded degree is in mechanical engineering).

Several programs offer a biomechanics concentration or track within the broader BME/BioE graduate program, including:

- Yale University
- University of Pittsburgh
- University of Michigan
- University of Iowa
- University of Illinois at Urbana-Champaign
- University of Akron
- Temple University
- Rensselaer Polytechnic Institute
- New Jersey Institute of Technology
- Marquette University
- Case Western Reserve University
- Drexel University
- Johns Hopkins University (mechanical engineering)

Concentrations or tracks usually refer to a collection of required and elective courses that students may select, reflecting on their desire to focus on the sub-area or sub-discipline while pursuing the broader degree.

As part of the academic infrastructure, many BME/BioE programs have a dedicated research group and an associated laboratory. These entities tend to be more multidisciplinary in nature, often including both engineers and physicians. Examples of such defined entities that are based in engineering include:

- Injury and Orthopaedics Biomechanics Laboratory (Duke University)
- Orthopaedic Biomechanics Laboratory (Michigan State University)
- Orthopaedic Biomechanics research group (Purdue University)
- Injury Biomechanics Laboratory (University of Pennsylvania)
- Biomechanics Research Laboratory (University of Southern California)
- Applied Biomechanics Laboratory (University of Washington)
- Center for Injury Biomechanics (joint program between Virginia Tech and Wake Forest)
- Orthopedic Biomechanics Laboratory (University of Iowa)
- Biomechanics Research Laboratory (University of Illinois at Chicago – Mechanical Engineering)
- Neuromuscular Biomechanics Laboratory (Stanford University)
- Soft Tissue Biomechanics Laboratory (University of Arizona)
- UW Neuromuscular Biomechanics Laboratory (University of Wisconsin-Madison – Mechanical Engineering)
- Laboratory for Neuroengineering (includes the Neural Injury Biomechanics and Repair Laboratory) — joint program between Georgia Tech and Emory University

While not a formal laboratory, the impact biomechanics group at Wayne State University includes several BME faculty members. The Injury/Impact Biomechanics Laboratory at University of Michigan is housed within the Transportation Research Institute. In addition to the engineering-based entities, some research entities may be based in a medical school or health sciences complex. For example, the Spinal Column Biomechanics Laboratory at Johns Hopkins University is based within the medical school, but engineering faculty plays a significant role. Also, the Injury Biomechanics Research Center at Ohio State University is housed within the College of Medicine but is staffed (and directed by) engineering PhDs. The Center for Injury Biomechanics at Wake Forest

University is based within the School of Medicine but is a part of the Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences.

No biomechanics courses were identified for any of the MD, DO, or DC programs. To be more specific, there was no evidence that any biomechanics courses were required as part of the academic requirements (or as elective courses) for any of these degrees.

Figure 4 presents examples of textbooks (currently in print) in basic/general biomechanics and also in injury biomechanics. As included in the information, almost all of the authors/editors are PhD scientists/engineers; only a few are MDs.

Many engineering technical societies have divisions or sections that focus on biomechanics. For example, the annual meeting of the Biomedical Engineering Society (BMES) has a biomechanics track as one of its major areas of focus. This usually includes specific sections on injury biomechanics. This is also true of the American Society of Mechanical Engineers. The American Academy of Forensic Sciences (AAFS) includes a forensic engineering sciences division. Many of the presentations and publications focus on injury biomechanics and are authored by engineers. The Society of Automotive Engineers (SAE) publishes many significant papers in the area of injury biomechanics. The National Academy of Engineering (NAE) and the National Academy of Forensic Engineers (NAFE) routinely publish the works of engineering biomechanists.

Other societies may be broader in membership in terms of their academic disciplines, but still include a significant engineering presence. For example, the Association for the Advancement of Automotive Medicine (AAAM) publishes many papers on injury biomechanics authored by engineering investigators. The European Society of Biomechanics also involves many engineering contributors.

An inspection of the peer-reviewed literature in a wide variety of journals readily indicates a strong

Basic/general biomechanics

Basic Biomechanics of the Musculoskeletal system
4th edition, Lippincott Williams & Wilkins, 2012
M. Nordin (PhD Medical Science);
V. H. Frankel (MD, PhD)

Basic Orthopaedic Biomechanics and Mechano-Biology
3rd edition, Lippincott Williams & Wilkins, 2004
V. C. Mow (PhD) and R. Huiskes (PhD)

Biomechanics: Mechanical Properties of Living Tissues
2nd edition, Springer-Verlag, 1993
Y. C. Fung (PhD)

Biomechanics of the Musculo-Skeletal System
3rd edition, Wiley, 2003
B. Nigg (D.Sc.) and W. Herzog (PhD)

Biomechanics: Principles and Applications
2nd edition, CRC Press, 2008
D. R. Peterson (PhD) and J.D. Bronzino (PhD)

Fundamentals of Biomechanics
2nd edition, Springer, 2007
D. Knudson (PhD)

Fundamentals of Orthopaedic Biomechanics
Williams & Wilkins, 1994
A.H. Burstein (PhD) and T.M. Wright (PhD)

Tissue mechanics
Springer, 2007
S. C. Cowin (PhD) and S. B. Doty (PhD)

Injury biomechanics

Accidental Injury: Biomechanics and Prevention
3rd edition, Springer, 2014
N. Yoganandan (PhD) and A. M. Nahum(MD)

Biomechanics of Impact Injury and Injury Tolerances of the Head-Neck Complex
Society of Automotive Engineers, 1993
S. H. Backaitis (Principle Engineer, NHTSA)

Biomechanics of the Upper Limbs: Mechanics, Modeling, and Musculoskeletal Injuries
2nd edition, CRC Press, 2011
A. Freivalds (PhD)

Biomechanics of Musculoskeletal Injury
2nd edition, Human Kinetics, 2008
W. C. Whiting (PhD) and R. F. Zernicke (PhD)

Trauma Biomechanics: Accidental Injury in Traffic and Sports
3rd edition, Springer, 2010
K. U. Schmitt (PD Dr), P. F. Nieder (Dr),
M. H. Muser (Dr Med), and F. Walz

Figure 4
Examples of basic/general biomechanics textbooks and textbooks focusing on injury biomechanics.
In all cases, the highest degree of the author/editor is indicated.

presence of engineering investigators who focus on injury biomechanics. This includes both technical-focused journals and more medical journals.

As a final observation, it should be noted that federally funded research into injury biomechanics has significant engineering involvement. A number of engineering research centers were identified above; these collectively receive significant federal funding to accomplish their research missions that focus on biomechanics, specifically (in most cases) injury biomechanics. Other federally funded organizations that have an aspect of injury biomechanics (and therefore significant engineering participation) include the National Highway Traffic Safety Administration (NHTSA), the National Transportation Safety Board (NTSB), and the Consumer Product Safety Commission (CPSC). Other federal groups provide research funding for engineering biomechanics as part of their mission, including the Department of Veterans Affairs (VA), National Institutes of Health (NIH), and the National Science Foundation (NSF).

Discussion

As noted above, 92.3% of engineering programs have at least one defined course in biomechanics. All programs have one or more "survey" classes at both the undergraduate (when offered) and graduate level, including biomechanics as a core subject within the explored sub-disciplines. For example, *Introduction to Biomedical Engineering*[8] has a dedicated chapter on biomechanics. Similarly, *Biomedical Engineering Fundamentals*[9] includes a biomechanics chapter. Most BME programs also include biomaterials as a core subject — a field that overlaps and complements biomechanics.

Because of accreditation, programs in all the health degrees (MD, DO, and DC) are standardized, showing little variability in curricular issues, particularly in the first two years of study. The emphasis is clearly on the preparation of students to enter clinical practice. This may involve additional residency and other postgraduate training. Many MD programs and some DO programs offer interested students the possibility of pursuing MS and PhD degrees in a variety of subject areas, often including biomedical engineering. These degrees may be in parallel to their basic degree or postgraduate work. Most students do not seek this option. For example, according to the AAMC website for 2014-2015, there were 18,704 MD graduates, but only 616 MD/PhD graduates. As a result of such programs, there are a limited number of health care professionals who have pursued advanced topics in biomedical engineering (including biomechanics). Most MD/PhD students opt for doctoral studies in a medical science.

It should be noted that "biomechanics" is included as a subject area with osteopathic programs. For example, the biomechanics of movement is a common topic in broader classes. Also, courses in adjustment and manipulation will often touch on biomechanics. This is also true of many chiropractic programs. For example, the *Textbook of Clinical Chiropractic: a Specific Biomechanical Approach*[10] is used in many programs. In general, there is comparatively little emphasis on the original injury mechanisms and the broader biomechanical behavior at the tissue and functional unit level.

Historically, a few of the pioneer programs in BME came up through electrical engineering. More recently, BME programs may develop within other engineering disciplines, including chemical engineering and mechanical engineering. In general, the EE-influenced departments tend to have less emphases in biomechanics than those that came up through other engineering disciplines or alternately developed more recently as freestanding departments/programs with no historical departmental affiliations.

No biomechanics courses were identified for any of the MD, DO, or DC programs. This is not surprising when one considers that these are degrees designed to prepare students for the clinical environment. As a result, the ability to render biomechanics opinions by holders of these degrees (in the absence of any other degrees in engineering) is limited. Furthermore, the typical pre-professional curriculum (for example, a typical pre-med degree) has a minimum of physics courses (usually one year) and calculus (usually one year). Thus, a physician's ability to understand and perform basic analyses using statics, dynamics, behavior of materials under load, and the other tools of biomechanics are also limited. As noted in the introduction, a common claim of many attorneys is that any sort of biomechanics-related opinion is best provided by a physician. Schneck[11] observes:

> *In defense of the medical establishment, let me add quickly that clinicians are concerned more with the diagnosis and treatment than*

> *with causation. Thus, they tend to justify their opinions in a rather cavalier fashion – not by hard, objective quantified evidence on which to base a conclusion "to a reasonable degree of scientific certainty," but by soft, subjective, qualitative conjecturing that goes something like this: "look, patient says he (or she) was fine prior to the incident in question, and I have not really dug deep enough or hard enough to assume otherwise, so I arbitrarily take his (or her) word for it."*

Again, typical health care professionals basically have minimal to no training in the biomechanics area as part of their professional training (including pre-professional academic pursuits). Two potential exceptions to this would be a student who earned a BS (or higher) degree in a relevant engineering discipline as their pre-professional degree(s) or physicians who earned advanced engineering degrees either in parallel to their professional training or post-graduate work.

One area of supporting evidence not included in this analysis is the biomechanics-related peer-reviewed literature. This is voluminous. Journal articles on any topic of biomechanics are easily located. In the preponderance of these articles, the authors are affiliated with some BME/BioE/ME department or program. It should be noted that older articles (for biomechanics, "older" means pre-1970), many of the authors would have been affiliated with traditional engineering departments, since BME/BioE was just starting to emerge as a freestanding program or department in the 1970s. The Biomedical Engineering Society was founded in 1968, reflecting the emergence of this engineering discipline during the latter half of the 20th century. The first accredited BS programs in BME occurred in 1972 (Duke University and Rensselaer Polytechnic Institute)[12].

More recently, the term "forensic biomechanics" has come into use (the term "forensic engineer" has been around for a longer time). This term acknowledges that engineering biomechanics has become a part of the litigation process in situations involving potential or demonstrated injury. Schneck[11] observes:

> *What, then, is "forensic biomechanics"? This term is relatively new to the legal industry, but gaining in popularity as the general field of biomechanics grows and matures. Stated simply, forensic biomechanics applies biomechanical knowledge to answer certain questions of civil and criminal law … Biomechanics, then, involves the application of the science of mechanics to biological things, including the human body. Among numerous diverse activities, biomechanical engineers deal with subjects such as the body's response to sub-gravity environment; vehicular impacts; work—and sports-related stresses and strains … Our judicial system must recognize that the forensic biomechanical engineer – not the treating physician, not an ergonomist, not any other type of "expert" – is the one most qualified to tender legal opinions as to causation in civil and criminal matters when the cause of a medical affliction clearly involves biomechanical issues.*

The information presented above clearly indicates that biomechanics is a subject area well-established within the field of engineering. Biomechanics research groups and laboratories are found throughout the engineering environment. To say that biomechanics is *not* a matter of engineering but rather one of medicine is simply uninformed and erroneous.

Regarding the protocol of how to conduct a biomechanical analysis, this has been addressed in detail in many peer-reviewed publications (for example, Lee[13] summarizes other protocol references). As practiced by biomedical engineering experts throughout the country, the general protocol regarding the analysis of a claimed injury-causing event (regardless of the retaining party) involves:

- body motions in response to applied forces (the physics of the event may be determined by a separate expert).
- the determination of any associated forces (including magnitude, direction, and area of the body affected).
- the establishing of (or lack of) any injury mechanisms for injuries of the type claimed.
- the extent to which any applied forces may exceed relevant injury thresholds. In many situations, it may also be useful to cite the forces associated with so-called Activities of Daily Living[14].

Recent Florida courtroom decisions have supported the viewpoint that biomedical engineering expert opinions regarding injury biomechanics assist the trier of fact. From the recent ruling in *Council v. State*[15], excluding the testimony of a biomedical engineer/biomechanics expert is an abuse of discretion. The boundaries of a trial court's discretion to admit or exclude evidence are confined by Florida's evidence code and controlling case law[16]. Court decisions have established that: 1) a fundamental cornerstone for analysis is that all relevant evidence is admissible, except as provided by law[17] and 2) relevant evidence may be inadmissible where its probative value is outweighed by the danger of unfair prejudice[18]. Florida courts have held that if relevant evidence is not unfairly prejudicial, the trial court has no discretion or authority to exclude it[19]. In summary, the decision in *Council v State* provides controlling Florida case law to support the conclusion that the proffered testimony of a biomedical engineer/biomechanics expert may be relevant to the issues of causation, including the disputed issues concerning velocity and the directionality of forces involved in an accident. If a trial court elects to discount and discard the authority of the *Council* case, the appeals court has been clear that excluding a biomedical engineer/biomechanics expert is an abuse of discretion.

Conclusion

The ability of a forensic biomedical engineer to offer opinions related to biomechanical issues (specifically including injury biomechanics) is well-grounded within the engineering discipline. Contrary to the beliefs of many (including non-engineers and attorneys), biomechanics is not the exclusive turf of medical sciences. Just because one holds a traditional MD, DO, or DC degree, he or she is not automatically qualified to render biomechanics opinions. In fact, biomechanics is a subject that is virtually absent from the pre-health care professional academic curriculum. On the other hand, biomechanics is an academic subject routinely included in the engineering curriculum, both at the undergraduate and graduate program levels. The foundations upon which biomechanics are based, including statics, dynamics, materials science, modeling, and knowledge of human tissue anatomy/behavior is well-integrated within biomedical engineering education and research. Most health care professionals were exposed to minimal physics and associated mathematics in their undergraduate training; it is basically not significantly relevant to their future clinical careers. Research groups and laboratories focusing on biomechanics are found throughout engineering programs and beyond (for example, aspects of automotive and consumer product safety). Relevant literature (journal articles, books, etc.) is dominated by engineering investigators and practitioners. To say biomechanics is *not* a matter of engineering (but rather one of medicine) is unsupportable.

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