A Cadaver Study Revisiting the Original Methodology of Lauge-Hansen and a Commentary on Modern Usage

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Background: The study by Lauge-Hansen published in the Archives of Surgery in 1950 still stands as the seminal work for our understanding of the pathomechanics of ankle fractures. The purpose of the present study was to recreate Lauge-Hansen’s experiments for the supination-external rotation (SER) fracture mechanism and to determine whether the predicted sequence of osseous and soft-tissue injury is reproducible on the basis of his originally described methodology.

Methods: Ten fresh-frozen cadaver specimens amputated above the knee were utilized. The foot was axially loaded in a position of neutral dorsiflexion and supination. External rotation was applied manually in accordance with Lauge-Hansen’s description until osseous and/or soft-tissue injury occurred. Fluoroscopic images were made and anatomic dissection was performed.

Results: Although several specimens exhibited findings consistent with certain stages of the SER injury pattern, no specimen demonstrated the complete sequence of predicted osseous and soft-tissue injury.

Conclusions: Loading cadaver specimens with an SER mechanism utilizing a methodology similar to that in the original experiments by Lauge-Hansen does not reliably produce the sequence of osseous and soft-tissue injury predicted by Lauge-Hansen.

The mechanistic classification of ankle fractures developed by Niels Lauge-Hansen arose from a series of cadaver studies in the 1950s in which freshly amputated specimens were fractured by hand1–3. On the basis of these experiments, Lauge-Hansen reported that characteristic and reproducible patterns of osseous and soft-tissue injury occurred, depending on the position of the foot and the direction of the deforming force. This led to his classification system, which has stood as the seminal work for our understanding of how ankle fractures occur.

The supination-external rotation (SER) ankle fracture pattern is the most common injury pattern observed4–6. Stage I in the SER injury pattern involves failure of the anterior inferior tibiofibular ligament or a Chaput-Wagstaffe distal tibial or fibular avulsion fracture, stage II involves a short oblique distal fibular

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fracture, stage III involves failure of the posterior inferior tibiofibular ligament or a posterior malleolar fracture, and stage IV involves deltoid ligament disruption or a medial malleolar fracture.

Lauge-Hansen’s work was a landmark achievement at that time as it correlated radiographic findings with injury mechanisms, allowed surgeons to predict additional soft-tissue injury, aided in fracture reduction, and assisted in the closed treatment of fractures in an era predating modern surgical techniques. However, over the past several decades, multiple studies utilizing biomechanical and radiographic as well as video analyses have failed to validate Lauge-Hansen’s mechanistic theory. Despite these challenges, the Lauge-Hansen classification is still widely used to this day.

The purpose of the present study was to recreate the Lauge-Hansen study with regard to the SER mechanism and to determine whether the described injury patterns are reproducible utilizing his originally described methodology. We hypothesized that the SER mechanism would not reliably and consistently produce the predicted sequence of osseous and soft-tissue injury.

Materials and Methods

The study utilized ten fresh-frozen cadaver specimens, amputated above the knee, without a history of lower extremity pathology, which had been thawed for twenty-four hours prior to experimentation. Initial fluoroscopic images were obtained to confirm the absence of preexisting osseous pathology. DXA (dual x-ray absorptiometry) scanning was performed to assess bone mineral density. In accordance with Lauge-Hansen’s original methodology, skin and subcutaneous tissues superficial to the fascia were removed from the dorsum of the foot, the ankle, and the distal 10 cm of the leg. The soft tissues surrounding the femoral shaft were removed to allow the femur to be clamped in a vise.

Each specimen was tested in a standardized fashion. The foot was fixed to an 8 × 16-in (20.3 × 40.6-cm) sheet of 3/4-in (1.9-cm) plywood with use of multiple drywall screws. The femur was then fixed in a vise at an angle of...
approximately 45°, resulting in approximately 45° of knee flexion (Fig. 1). Using the plywood board, the ankle was placed in neutral dorsiflexion, manually axially loaded, and then supinated until firm tension was achieved. This was considered maximal supination as described by Lauge-Hansen. The ankle was then rapidly externally rotated until firm resistance was met, at which point external rotation was increased until a crack, tearing, or other substantial audible or tactile sensation was detected. Visual and fluoroscopic examinations were then performed to determine which structures, if any, were injured.

The experiment was deemed completed at this point if the ankle exhibited both medial and lateral instability, whether resulting from fracture, ligamentous injury, or both. This instability was determined by gross inspection as well as by fluoroscopic stress images in an external-rotation stress test. However, if there was no obvious lateral injury, if there was no medial malleolar fracture or deltoid disruption, or if the external rotation stress test did not produce at least a 5-mm increase in the medial clear space, the ankle was deemed stable and the experiment was resumed. The previously described foot position was resumed and external rotation was increased until further evidence of injury was seen, heard, or felt. This process was repeated until the injury was deemed complete and/or the ankle joint was grossly unstable, so that each specimen had theoretically undergone all four stages of the SER mechanism as described by Lauge-Hansen.

Final fluoroscopic images involving anteroposterior, mortise, and lateral views were made to demonstrate the final injury pattern. Each specimen was then thoroughly dissected to visually inspect and identify all injured structures (Table I) and fracture fragments.

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There was no external funding for this study.

**Results**
The mean age of the specimen donors was 65.4 years of age (range, thirty-six to eighty-four years); five of the donors were male. No specimen was osteoporotic as measured by DXA scanning, and all were free of any osseous pathology. The anatomic findings are described in Table I, and the corresponding Lauge-Hansen stages are summarized in Table II.

Four specimens exhibited a short oblique distal fibular fracture; two of these were the above-mentioned specimens with failure of the anterior inferior tibiofibular ligament, consistent with stage I progressing to stage II of the SER pattern (Fig. 2). Therefore, four of the ten specimens exhibited an osseous injury characteristic of stage II, and only two of these exhibited the complete pattern predicted for a stage-II injury.

The posterior inferior tibiofibular ligament was disrupted in one specimen, and the injury in this specimen was associated with a short oblique fibular fracture but not with a stage-I injury. No posterior malleolar fractures were created. Therefore, one of
the ten specimens exhibited an injury characteristic of stage III, and no specimen exhibited the complete pattern predicted for a stage-III injury.

One specimen exhibited a medial malleolar avulsion fracture (Fig. 3), and another exhibited a vertical medial malleolar fracture consistent with the supination-adduction pattern (Fig. 4). Both of these medial malleolar fractures were associated with a fibular avulsion fracture. Four specimens exhibited a deltoid ligament rupture. One of these deltoid injuries was associated with a short oblique fibular fracture, and five of five produced the characteristic stage-II injury with additional dorsiflexion in this position. Haraguchi and Armiger applied a pronation-external rotation force, with and without an additional lateral force, to twenty-three cadaver ankles. They demonstrated that both short oblique fractures (consistent with the SER pattern) as well as high fibular fractures could be produced, depending on whether an additional laterally directed force was applied to the foot, challenging the importance of foot positioning. Stiehl et al. loaded twenty-six ankle specimens in external rotation and similarly found little correspondence between foot position and injury pattern. Additionally, they found that the injury pattern differed markedly between specimens from male and female donors, with the latter sustaining a transverse fibular fracture without syndesmotic or deltoid injury in 45% of cases. Additionally, they were only able to produce seventeen oblique distal fibular fractures, and only thirteen of these cases had evidence of an associated injury of the anterior inferior tibiofibular ligament.

Others have used advanced imaging modalities such as MRI (magnetic resonance imaging) and found a similarly poor correspondence between in vivo imaging findings and the ligamentous injuries predicted by Lauge-Hansen. Gardner et al. evaluated forty-nine ankle fractures with use of MRI. Radiographs were assigned a fracture classification by an experienced orthopaedic traumatologist, and MRI studies were evaluated by a musculoskeletal radiologist for integrity of the ankle ligaments. Poor correspondence was found between the actual ligamentous injuries and the soft-tissue injuries predicted on the basis of the designated Lauge-Hansen classification.

In a previous study, our group utilized video analysis of subjects who sustained ankle fractures under physiologic loading conditions and found a similarly poor correspondence between the predicted fracture pattern and the actual radiographic findings. Utilizing injury videos obtained from the web site www.YouTube.com, we were able to match the foot position and deforming force visualized on video with the resulting fracture pattern seen on radiographs obtained from the study participants. In this initial case series of fifteen subjects, we found that the Lauge-Hansen system was accurate in only 58% of injuries caused by the supination-adduction and pronation-external rotation injury mechanisms. In a follow-up study utilizing the same methodology, we reported on a larger cohort of thirty subjects (including the fifteen from the earlier study). In that series, we found that the Lauge-Hansen classification system was
65% accurate in predicting fracture patterns on the basis of the deforming injury mechanism. Additionally, we found no video evidence of SER injury mechanisms, which was surprising given that the SER pattern has been demonstrated to be the most common ankle fracture pattern. However, this lack may have been due to selection bias, as the majority of videos demonstrated skateboarding injuries (which, by the nature of the activity, may predispose to certain injury mechanisms other than SER).

Our thoughts in initiating this study were to determine whether Lauge-Hansen’s results could be replicated utilizing a methodology similar to the one he utilized over half a century ago. We recognized that duplication of his results would have merely demonstrated reproducibility and would not have validated the mechanistic theory, as it can be argued that findings from manually fractured cadaver specimens do not necessarily translate to in vivo injuries sustained under physiologic loading. However, an inability to replicate his findings utilizing a methodology nearly identical to that in the original work does call into question the validity of the purported sequential order of osseous and ligamentous injuries that Lauge-Hansen reported in his experiments.

Ankle fractures are produced by a combination of deforming forces including rotation, angulation, axial loading, and translation. The video analysis in our group’s previous research illustrates this point, although the various deforming forces resulting in the ankle fractures in those subjects were not quantified. These forces are applied to a body in motion, and the forces transmitted across the ankle joint along various vectors changing with various velocities are not reproducible with use of a loading apparatus as described by Lauge-Hansen. Unlike Lauge-Hansen’s original experiments in which the leg was fixed and the free foot rotated, fractures in vivo usually occur with the foot fixed (load-bearing) and the body in motion, creating multiple applied forces across the ankle joint.

Recognition of methodological difficulties in the original work and failure of subsequent biomechanical, radiographic, and video analysis studies to validate the mechanistic classification system raise the question of why the orthopaedic community continues to utilize the Lauge-Hansen classification system. If the level of current evidence fails to substantially call into question the validity of the classification system, then it is unclear what additional investigations will. This question is compounded when the classification’s complexity, poor interobserver reliability, and lack of prognostic capabilities are considered. In general, classification systems are thought to be useful if they are valid, reliable, and prognostic and they help guide treatment. To evaluate the current opinions of orthopaedic surgeons, we conducted an electronic survey of 950 practicing orthopaedic surgeons, of whom 29% responded. Surgeons were asked their opinions on various topics regarding the Lauge-Hansen classification. Of the 274 respondents, 51% did not utilize the Lauge-Hansen classification when evaluating ankle fractures, 61% felt that the classification was not sufficiently validated, 70% believed that the classification was too complex and should be replaced with a more user-friendly classification, 75% felt that methodological deficiencies raised questions regarding the classification’s applicability to injuries sustained in vivo, and 56% believed that the classification system was largely historical and was not relevant to the treatment of ankle fractures.

Despite its known limitations and questionable validity, the usage of the Lauge-Hansen classification system continues. This is likely because it represents an effective descriptive classification, which can be explained by a psychological theory known as mental association (also termed the association of ideas) that examines the conditions under which representations arise in consciousness and the succession of mental thought processes. For example, a house officer’s description of an “open SER 4 ankle fracture” to the on-call staff in an emergency department initiates the mental phenomenon of association as descriptive information regarding the fracture pattern is relayed and surgical intervention and the mode of fixation are considered. One tenet of the theory, called the law of contiguity, explains this phenomenon of mental association. In such an example of the law of contiguity, the mere sight of an object reminds one of its name, or the name creates a mental image of the object, irrespective of the origins of this association. Although the staff surgeon in our vignette may not recall the intricacies of the Lauge-Hansen classification, the mental association (“SER 4” equating to an image of an ankle fracture with a characteristic fracture pattern) is ingrained in the minds of most orthopaedists. This association was long established through our training, with continued testing of this classification system in in-service training or board examinations as well as in our clinical experiences. As such, the descriptive benefit of the classification system appears to supersede concerns based on questions of validity and hence leads to continued usage of the classification. Once the mental association has been established, rational challenges to the validity of the association (such as the results of Michelson, Haraguchi, Gardner, Rodriguez, Kwon, and others) fail to dissociate the ideas or to dissuade usage. J.S. Mill, an important figure in the development of the theory, wrote: “When two phænomena have been very often experienced in conjunction, and have not, in any single instance, occurred separately either in experience or in thought, there is produced between them what has been called Inseparable, or less correctly, Indissoluble Association: by which it is not meant that the association must inevitably last to the end of life—that no subsequent experience or process of thought can possibly avail to dissolve it; but only that as long as no such experience or process of thought has taken place, the association is irresistible; it is impossible for us to think the one thing disjoined from the other.”

There are several strengths and weaknesses of the present study that should be examined in the context of its goals. It was our intention to replicate the methodology and techniques that Lauge–Hansen utilized. Therefore, for example, uncontrolled, nonphysiologic loading of the cadaver specimens should not be considered a weakness of this study. Rather, one strength of the present work is that the protocol described by Lauge–Hansen for his SER experiments was strictly followed. The cadaver specimens were stabilized with a vise clamp with the foot affixed to a wooden board as described in the original work. The specimens were fractured by hand, duplicating Lauge-Hansen’s described technique for each stage of injury. Radiographs were made and
dissection was performed as described in the original work. One weakness and deviation from the original protocol was the use of fresh-frozen rather than freshly amputated cadaver specimens. Modern rules and regulations necessitated this modification, as preparation of cadaver specimens for scientific purposes is highly regulated, as is the custody of freshly amputated limbs. Freezing and embalming agents have known effects on the mechanical properties of bone, tendon, and ligamentous structures, but they are unlikely to have substantially affected our results. Although the mean age of our donors was 65.4 years (range, thirty-six to eighty-four years) and the majority of ankle fractures occur in a younger population, the absence of osteoporosis (as determined by DXA scanning before the testing) likely eliminates the possibility of substantial differences in results due to donor age. Furthermore, although Lauge-Hansen described many aspects of his experiments in detail, others details were left undescribed and our protocol may therefore have differed slightly. For example, ankle position (i.e., the amount of dorsiflexion or planter flexion) was not described for stage-I injuries. Similarly, application of lateral forces, although implied, was not carefully detailed. Another weakness of the present study is that we only stressed our specimens in an SER mechanism and other mechanisms were not examined. We chose to focus on the SER mechanism because multiple studies have demonstrated the SER fracture pattern to be the most common. Thus, we cannot comment on the reproducibility of Lauge-Hansen's work as it applies to supination-adduction, pronation-external rotation, or pronation-abduction injuries.

In conclusion, the continued usage of the Lauge-Hansen classification should be questioned in light of its methodological difficulties, its questionable validity, and the failure of subsequent studies to replicate the expected patterns of injuries as proposed in the classification system.

References


