DISCUSSION OF MORNING PAPERS

Dr. Basmajian: Let's start the discussion by addressing any questions that you have for the speakers.

Dr. Kelly: I'd like to direct my question to Dr. Sutherland. Number one, if you're going to do this sort of analysis, can you combine it with evaluations of the muscular involvement?

Dr. Basmajian: I think all three speakers (Milner, Simon, Sutherland) can answer this question after David leads off.

Dr. Sutherland: We do simultaneous electromyography along with movement measurements and force plate recording. We use surface and internal electrodes and our attention is directed primarily to obtaining the off and on time of selected muscles. There is a great value to knowing the timing of muscle contraction as it relates to the events of gait, but I think that we cannot rely upon the electromyograms as we now do them to give us quantitative information about the force of muscle contraction. As you know, Dr. Perry is doing work on quantitation of the electromyograms utilizing a computer program to measure the area under the curves of the muscle action potentials. We are investigating the relationship of intramuscular pressure to muscle tension and are currently testing a miniature solid state pressure transducer which can be inserted percutaneously into the muscles. But even if we do develop a satisfactory method of assessing muscle tension, there are still many problems. The absence of action potentials during the performance of a movement is good evidence that the muscle is not contributing to the movement, but the presence of action potential or recordable tension in the muscle only tells us that this muscle is activated during the time that movement occurs and possibly the degree of activity or tension. To obtain the full picture we must have knowledge of all the other muscles that might affect the movement and inertial and gravity forces which affect the movement must also be considered.

Dr. Basmajian: Thank you. Are there any other comments along this line? Those of you who have seen and heard Paul Brand lately perhaps know that he is emphasizing muscle bulk in evaluating its potential usefulness in muscle transfers. He shows slides of practically every muscle in the body laid out to show their variation in size, the characteristic of the direction of fibers of the muscle, and the potential usefulness of this in determining the force that the muscle would exert--or at least the force that muscle would exert at a particular joint.

These are very contentious issues. It is true that electromyography is relatable to force, and yet the problem has arisen repeatedly that forces have been measured only in an isometric fashion; all that tells us is that this muscle is bigger than that muscle. These are facts we have known anyway. So the ability of gait laboratories to come up with a diagnosis of the contribution that a muscle is making to a particular action in normal or abnormal gait, is going to be very, very difficult.

Dr. Burstein: Let me ask a question. There are several gait laboratories now in existence that have devoted considerable time to measuring parameters from which they can calculate muscle force during various activities. There are several calculation schemes that look very promising, the University of Iowa, for example has developed an interesting optimization method. It now becomes a matter for the investigator to put together a clever test in which he can then evaluate the capability of the performance of a particular muscle or muscle groups. For example, if he is to do a transplant on a particular muscle, then he would have to require the patient to perform a task utilizing that particular muscle. The experimental and analytical techniques do exist but are not being employed. One reason that nobody is dealing with it, to my knowledge, is that nobody's trying to evaluate performance by imposing a particular path. Most of us are interested in the problems of walking, running, climbing up and down stairs. But we haven't progressed far enough in terms of the sophistication of our experiments, not necessarily in terms of the sophistication of our measuring technique, or in terms of the accuracy of the data we collect.

Dr. Basmajian: Dr. Burstein, are there two ways then of approaching the problem? Is the first gait recording, and the other, biomechanical and electromyographic techniques, divorced from the gait training?

Dr. Burstein: Yes, there really are two ways. When Dr. Milner spoke, he showed us a table of information. I would like to bring up one point: i.e. the concept of linear force in joints. He emphasized it; he talked about forces in bones, forces in joints, forces in muscles. These forces aren't measured in any of those laboratories; they are all calculated. We do have the capability of calculating them; they are a mathematical imprint. Some special assumptions have to be made of course, but we have ways of verifying these assumptions and we are turning out some reasonable numbers. The "direct measurements" are EMG or muscle pressure, those phenomena related to muscle activity in functions that we're trying to relate to the occurrence of the force, or to the magnitude of the force. The EMG signal is obviously responsible for producing the force. On the other hand, the internal muscle pressure is a direct result of the force. Those are different kinds of measurements, and we hope that we can get direct transducer measurements that have a straight line output/force relationship. This development is in the future. The approaches we already have, do have the capability of quantitating the force.

Dr. Basmajian: Ed Chao, do you have a comment to make on that?

Dr. Chao: Direct and indirect verifications of theoretically calculated joint and muscle forces are possible. The use of instrumented joint prostheses to monitor the joint contact force and compare it with the theoretically predicted force would be classified as a direct verification method. There are other direct methods too. These methods include measuring hand flexor tendon tension using strain gauges in patients undergoing carpal tunnel release under local anesthesia; using muscle force transducers or applying strain gauges to bone in experimental animals and measuring intramuscular pressure to relate to contractive force. However, these direct methods lack reliability, repeatability, and they are impractical for human

use. The instrumented prosthesis has yet to produce any realistic results. Using animals as models requires a separate mathematical analysis, since the structure and behavior of animals would be different from that of man. These problems lead to the need of an indirect method to verify the analytical results.

The use of quantitative EMG to correlate with the theoretically determined force can serve as an effective qualitative verification provided that the function involved will be primarily isometric. The literature in the past has documented that there is certain correlation between muscle force and its rectified and integrated EMG. If the externally applied force during isometric function is increased incrementally, then the subsequent increase in measured EMG response should provide certain qualitative verification. However, if the function involves joint motion then the muscle contraction force will be difficult to correlate with integrated EMG since muscles will have different functional lengths and their fiber response will be different.

In talking about verification, one important aspect has to be remembered. The advantage of analyzing biomechanical systems through theoretical modeling is not to achieve a precise description of the realistic biological system. In fact, it is nearly impossible to do so. However, the main goal of doing so is to provide a reliable trend so that results on a comparative basis can be objectively assessed. Through such analysis, upper and lower bounds of results can also be established which will be extremely useful in providing safety limits and minimum requirements of therapeutic treatments in joint disease patients. In this case, an exact experimental verification is not necessary.

Dr. Basmajian: Jacqueline Perry wants to speak next.

Dr. Perry: The EMG represents the intensity of the signal stimulating a muscle to contract. There now is good evidence this is proportional to the intensity of the muscle's contraction, i.e. its level of activity. Hence we can identify when and how much a muscle is working but not its resulting force. To learn the percent of intensity the muscle is working from the EMG signal, one must have a base line test relating EMG to measure maximum effort. There are several variables alerting this relationship, however. (1) The fact that shortening contractions accomplishes 30 percent less force than isometric or eccentric (yielding) types of activity. (2) Velocity of contraction reduces the muscle efficiency. (3) The three muscle fiber types have different capabilities of exhibiting force and different endurance tolerances. Hence to determine the force from an EMG requires a very complex mathematical model of which several factors still need more definition.

Dr. Basmajian: Jacqueline's remarks lead to a neurophysiological consideration. Before I call on Dick Stein, I might mention that underlying all this is the fact that active muscles may be playing no efficiency role--that is, muscles in children may be acting, but no demonstrable role can be assigned to them in the achievement of a movement through space. This has been shown over and over by electromyographic studies of youngsters in whom there is an excessive activity in muscles that are unrelated to what we would consider

to be a useful achievement. This is part of the pattern of growth; there is an excessive activity which is almost spastic in some babies, and this continues late into childhood, as late as junior high school age. And no one can assign any particular use to it. Czechoslovakian investigators have shown that when you ask a child to extend his knee while sitting on the edge of a table, for example, that the adductors of the hip joint act very, very strongly; but with growth this gradually disappears. By the time they are adults, or young adults, they are no longer using those muscles in extending the knee or in walking.

So you will find that there are EMG activities that cannot be related to purposeful movement, and this is all related to the maturation of the central nervous system and its control mechanisms. Dave Sutherland showed us slides of a number of graphs that he provides to surgeons, with an explanation of what they all mean. He has brought this work to the practical level, so that the surgeon, looking at the gait analysis can make judgments which are superior, we hope, to simply looking at the patient walk.

Dr. Simon, would you like to comment?

Dr. Simon: Dr. Sutherland, Dr. Perry, and Ms. Murray are notable in their achievements in illustrating not only how certain measureable parameters of gait can be clinically useful, but in presenting them in a form that is easily understood. There remains a considerable body of measureable or calculable information, whose value in assessing a variety of gait disorders is yet to be determined. In the past when they have been obtained, quantities such as angular and limb segment velocities, accelerations and energies, and joint forces, have all been considered to be important and useful. But these instances have been few. We are now in a favorable position to present these parameters in a clinically palatable form, and apply them to a wide variety of pathological disorders. I think some of our attention should be focused on doing this and ascertain in what instances information so derived is inherently useful and in what instance it is of more importance than simpler quantities.

Dr. Basmajian: I'd like to draw Dr. Houk into this conversation now.

Dr. Houk: I'm impressed by the technology that is being used to record many important variables, but I would like to question the use to which this technology is being put. I don't think enough thought has been given to the design of experiments that are capable of revealing important principles and concepts concerning the mechanisms by which gait and posture is controlled by the central nervous system.

Dr. Basmajian: Al Burstein has a further comment.

Dr. Burstein: We've had some pretty good descriptions of some of the major gait labs in the country. We then went into what I consider the major topic, first, the desire for normative data, and second, the need for scientific experiments. Then we started getting into the topic of how one uses these

tools in terms of clinical diagnosis. I think we've bounced back and forth, and, in my mind, I think we have to keep these topics separated. One seeks a collection of normative data as a scientific data base from which you can either do scientific experiments or develop new clinical diagnoses. One does a scientific experiment only if you have a hypotheses to test. But I think that if we keep going through the cycle as to what constitutes an experiment, what constitutes diagnosis, and where are we in the state of the art of instrumentation and normative development, we are going to become very confused.

What can we do in the gait laboratories? Obviously we can observe the limb. But we also have the capabilities of going within the limb, of looking at, for example, different stage of activity--basic activities. This tells us that they're part of the problem, different muscle forces being applied. We can diagnose specifically what the detailed differences are, and these are reflected grossly in the fact that what we have is an output--a limb motion. We must always remember of course, that we have an equilibrium system--we push it off equilibrium in one way, it tries to come back, and depending on how hard we push it, it may not come all the way back.

I also think that we can address ourselves to what kinds of serious scientific experiments can be performed in a gait laboratory. I think that's very germane. But you must pose a question. If you want to get right down to it you can write a proposal which says, I have a question that needs answering; it is justified on clinical grounds. I have to use a gait facility in order to obtain the information that will answer the question.

Question: Are serious experiments being done?

Dr. Burstein: Yes, I have spent some time talking to people who have gait laboratories and asked them what kinds of experiments they were doing. There are a good number that I would consider good scientific experiments.

Dr. Basmajian: I've introduced a simple hypothesis in recent years which everybody has ignored; that is, that human gait on a flat surface--walking gait--is bicycling--and has many of the characteristics of simple bicycle riding. I also think that footfall is really a portion of the circle of the wheel--a very large wheel in the case of human gait, that's rolling along in a two-wheel fashion. I would welcome anybody testing that hypotheses: I don't know how to do it myself. It's a concept rather than a hypothesis, perhaps. And remember, when we talk about locomotion, that walking on a surface is only a small portion of the capability of the human anatomy to move across the ground. There are many other aspects of gait--both human and vertebrate, that we have not addressed in the discussion so far.

Dr. Childress: Two or three statements have been made about the usefulness of optimal control theory in understanding gait. I should like to caution against being overly optimistic about the value of optimal control solutions. Experimentalists and theorists working on joint motion have been forced to consider optimal control because they have an indeterminate problem; many

more forces are developed by the musculature than are actually needed. The question then is what pattern of forces is developed in these muscles.

One approach to solving this problem is to assume the pattern used by the body is one which actually tries to minimize some performance index. However, this of itself is a problem because the performance index (if there is one) is unknown. Therefore, the procedure is to select some logical performance indices and see if the solutions agree in any way with those expected.

This is the crux of my thought. The forces must still be measured to show that an assumed performance index is indeed correct. Consequently, optimal control tends to avoid the problem of verification. If the forces must be measured to verify theoretical results why not emphasize the development of instrumentation to measure muscle forces. Then we would obtain the information desired and even a good approximation to the performance index could be determined by solving the inverse optimal control problem.

Even muscle measurements may not be sufficient because a very complex system is being studied. Each person may solve the problem of walking in a slightly different way, even though gait may be generally similar in different people.

Dr. Basmajian: Before concluding the morning session, perhaps we ought to come back to the question of costs, although we're not here to establish norms for the nation. What is the outlook for support in the immediate future for the kinds of research that are needed and the total cost to at least achieve these goals satisfactorily? Dr. Milner, you had an estimate--do you want to expand on that estimate? What would an adequate center cost?

Dr. Milner: Approximately $100,000 for equipment alone. Depending on the nature of the study undertaken, pertinent staff skills would have to be provided. Also amortization of equipment must be accounted for realistically.

Dr. Heiple: I think that cost is one question we have to address. The economic cost benefit rate does enter a Study Section's considerations, along with the scientific merit of a project. The cost benefit is often reflected in the priority score. We all make some kind of value judgment related to the expensiveness of propositions, as opposed to subjective judgment of the value of the data to be obtained to scientific knowledge, or possible clinical usefulness. I do not think that we're going to arrive at any qualitative answer to this today. If we simply refine our understanding of what the problems are that are being raised, and the kind of questions that need to be answered, I think it will have been worthwhile.

Dr. Childress: Dr. Milner has indicated his list of gait laboratories is not exhaustive. As we have several people here who are well acquainted with this field it would perhaps be appropriate to attempt to complete the list. Two gait labs in Boston are not listed ant there is another at Presbyterian St. Luke's Hospital in Chicago. Are there others?

Audience: Vanderbilt has one.

Audience: There is one at Cornell.

Dr. Basmajian: Would you glance at the list. Are there other centers that are not listed in the Table? That is not a large additional number. It should be possible to add that to the table before it's published.

Dr. Akeson: It will be important for participants to review the gait lab listing and to fill in any gaps. One of the purposes for this conference was to survey the existing facilities, and it is important that the list be comprehensive.

I would like to echo the comments of Dr. Heiple and Dr. Burstein with respect to the need to assess the scientific merit of the product of gait laboratories. Questions of need with respect to normative data gathering, effectiveness of construction of hypotheses, and suitability of experimental design are central to this workshop and will be addressed recurrently today. Cost effectiveness of this research will also be an obvious concern.

Dr. Basmajian: Biomechanic labs. Have they contributed something that's real, that justifies cost?

Dr. Leith: With the courage of the non-combatant, I would like to comment. I don't think I've ever seen the situation where the gap between applied clinical science and the basic sciences, was broader than I've heard this morning. I think Jim Houk and Tom McMahon have been perhaps excessively gentle in saying what I think they're trying to get across, which is that the field appears to be dominated by clinicians who have pressing practical problems to solve, but don't know quite how to go about it. And they haven't been talking enough to the Houks or McMahon's; and so the productive approach i.e. the research approach, is not being pursued. Until the gait people start talking more to the basic scientists they simply aren't going to have the productive research results that are needed.

Dr. Basmajian: Do you include the bioengineers with the clinicians, or with the basic scientists? Sometimes it's hard to tell.

We'll let Dr. Burstein have the last word before we go to lunch.

Dr. Burstein: In a meeting held last year, through the efforts of Ed Chao, some very important results were presented and I think really started a merger of clinicians and engineers and the basic scientists from the point of view of some very good analyses of joint function relating to certain surgical problems. But there's another whole area that we don't see clearly, and I want to leave you with a word on that. That is the contribution to the design aspect of some of these new plans that are being developed.