

CGA FAQ: Varus/Valgus Artifact & Cleveland Marker Set

Dear Sir,

We received from Mr. Richard Baker the following message concerning flaws in our protocol for collection of data in normal children (database available in CGA site). We are also sending our reply to Mr. Baker. We are interested in hearing the CGA's opinion about this issue. We would like to present these two letters for discussion.

Message One:

from: Mr. Richard Baker (<mailto:richard.baker@greenpark.n-i.nhs.uk>)

Paulo,

Hope you'll take this e-mail the right way! I'm on a mission to raise awareness of the critical importance of thigh markers/knee alignment jigs amongst the VICON users community.

I've been looking in detail at the normal datasets posted to the CGA site with references to a presentation I'll be giving at the VICON user group meeting in Dallas on the importance of accurate and **repeatable placing of thigh markers** (or **knee alignment jigs** if used). If these aren't placed repeatedly then the normal data shows high standard deviations for hip rotation profile and knee varus/valgus angle.

I'm afraid that your data exhibits this (the set from Dr Sang Hyun also shows it but unfortunately his data is a picture so I have no access to the underlying data). The average standard deviation of your hip rotation profiles is marginally over 9 degrees whereas Jeremy Linskill's and our data shows just under 6 degrees. You also pick up quite a large mean signal on the valgus/varus trace which looks very similar to the knee flexion extension trace. The knee varus/valgus trace should be fairly close to zero throughout its range and what you are actually picking up is "cross-talk" from knee flexion which is caused by a systematic error in the placement of the thigh markers/knee alignment jigs. It is our experience that if you place the Knee alignment jigs exactly on the medial and lateral epicondyles rather than using these as a guide for locating the knee axis then you will get data looking like this. This means your hip rotation profiles are about 10 degrees more internally rotated than if the thigh markers are placed correctly. Of course if you are consistent and compare your pathological data with your own normal database then the offset in varus-valgus and hip rotation is less of an issue. However the large standard deviations you are showing suggests that the data collection protocol is not all that consistent either.

Hope you don't mind me poking my nose into your data like this but I've been looking for a way to illustrate these problems for the talk in Dallas. Do you mind if I use your data for this purpose. I will not make any reference to the source of the data (and will even be positively misleading if you like!) and by the time I've played around with scaling factors etc the data will not be recognisable as that posted on the CGA site.

From the positive side you'll get an independent peer-review of your data collection protocol which should be useful!

Best wishes

Richard

Message two (reply):

from: Paulo Selber, MD
Gait Lab. AACD
Brazil

Dear Richard

Not only have I taken your e-mail the right way, I would also like that your mission in raising awareness amongst VICON users include the awareness of how much KAD used model is misleading, non precise and human error dependent.

Before beginning our gait exams here, we already knew VICON's embedded models and understood the KAD's proper alignment importance. The problem, was and still is aligning it in some patients.

Well, our Pt's have heard from different Lab's staffs and you wouldn't imagine how many techniques are posted in the name of the proper positioning of this jig. Which is the center of rotation of the knee or the instantaneous center if you prefer (as a good engineer), at all?

We hate this jig so much and the model behind it that our engineer is himself developing a new one, a virtual KAD as he will. This virtual data, will definitely define to VICON where the knee axis of rotation is at a certain time or amount of flexion during gait.

Instead of raising awareness of the "jigs" importance, I would rather suggest you to raise the will for its substitution and the model with it, to a new "jig method" which can be human error free.

We have now done about 800 full gait analysis mostly in CP. kids whom as you may well know have one of the major problems concerned to the hips transverse plane. Our staff knows and knew already the error we carried in our learning curve, to the point that when we compared our data to a source of other gait lab the only statistical difference found was exactly the one related to hip rotation, we had expected that.

These days, we compare our patients data in all respects to our normal data except the hip rotation. This figure, we know it from the literature.

You may freely mention our staff's name, that's god to us anyway, remember we're south of equador... you may also ask the folks from VICON (Oxford Metrics), about the number of e-mails they have received from us in the past recent years, concerning this issue and also about our intent to know the model profoundly so that we eventually will be able to change or even improve it.

Once more thank you for your analysis, don't even think of using it as example of how accurate one should be in placing the jig only, use it also and please as an example of how the model is not reliable, I can tell you even today, after all our lab's experience (for I don't consider us to being on the learning curve any longer), and awareness, problems in placing this damn jig still exist. We in fact need to somehow abolish it and not raise it.

Thank you very much for your input.

Warm regards.

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Thank you for your attention.

Best Regards,

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(Written by: Paulo Selber, MD / Wagner de Godoy, Eng)

Dear Paulo, Richard, and I'm sure many more interested subscribers,

I'm so glad you've raised this issue, and I admire your honesty, and I hope others will follow your lead! This was the actual reason why CGA was started - to provide a forum for such open discussion.

We of course noticed the artifact problem when we started using our Vicon system, and after much helpful advice from Richard, Jeremy Linskill (Dundee) and Michael Orendurff (Portland Shriner's), decided to abandon the use of the KAD.

The problem is, as anyone who has used it will know, that placement of the KAD is extremely critical and difficult to get exactly right. We now use the mirror technique (see <http://www.rs.polyu.edu.hk/gaitlab/fyp98/mirror2.jpg>) suggested by Jeremy to align the thigh wands as straight as possible - I've been quite happy with the results from this method so far (varus/valgus artifacts less than 10 degrees, which I consider to be acceptable).

I would be much happier, though, to find a more satisfactory and objective method. I guess the basic problem is the lack of suitable bony landmarks on the thigh. We really only have the femoral condyles to play with, and they are not very well-defined.

I wonder about the experiences of people who are using the alternative Cleveland marker set, since I noticed that Andreas, who has supplied most of the Cases of the Week, seems to achieve quite small varus/valgus artifacts with his Motion Analysis Corp. system in Vienna - see, e.g. </archives/29-06-98/kinem.gif> </archives/25-9-97/kinem.gif> or </archives/01-03-98/kinem.gif>

As you may know, the Cleveland set does not rely so heavily on bony landmarks, since it uses triads (although, of course, we don't usually like such things in Hong Kong!). However, I have never really understood the static calibration of this marker set - perhaps someone could enlighten me?

Once again - I'm so glad this issue has been raised!

Chris
--
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Chris,

In reponse to your email concerning the cleveland clinic methods and use of static trials:

I have been quite interested in this problem for the past 5 years. We currently see about 350-400 patients per year in our laboratory and looked closely at the **differences between the "Wand" marker set and the "Cluster" marker set (cleveland clinic)** to asses what differences, if any. We us a MAC high-res system with 6 cameras and the cleveland clinic marker set. The **new OrthoTrak software** allows for 3 different marker sets (cleve clin, helen hayes without static trial, and helen hayes with static trials). Orthotrak has been programmed to use the same medial and lateral knee and ankle markers to determine the respective joint centers. The **wand set (HH with static) uses the pelvic arrangement of R and L ASIS and Sacrum to determine the hip joint center** during static trial to complete the "triad" of points needed to construct the local coordinate system for the thigh segment (hip center, thigh wand, knee lateral marker). The **cleveland clinic set does not use the hip center as part of the triad but rather the 3 points on the lateral cluster (triad) to construct the local system.** With this local thigh orthogonal coord sys, the CC marker set references the lateral and medial knee point to the this system during the static capture and uses this reference to reconstruct the knee center during the dynamic trials. This being the case, lateral and medial knee and ankle points are not needed during walking for the CC set.

I am **completing research comparing the 2 sets during gait.** I put both markers on the body that would satisfy the algorithm of both marker sets and collected a static trial for each leg. The same static trial was used in the processing of both marker sets. Prelim results show **very close kinematic and kinetic comparisons between the 2 sets over 60**

normal children. These data will be available in poster form at the Gait conference in Dallas this week.

I would be interested in hearing any feedback on what you use in your lab and ideas for improvement

Patrick

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Dear subscribers,

I would like to try to use the "Cleveland marker set" for gait analysis but was unable to find any published paper describing this marker set. Could someone help me to find informations on this subject ? Many thanks by advance,
Stephane

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I have received many inquires on the Cleveland Clinic Marker Set and I thought I would publically answer the question since this set is only used by Motion Analysis gait and sports researchers alike.

The Cleveland Clinic Marker set is a proprietary marker set own by Motion Analysis Corporation, Santa Rosa CA. The CC marker set developed in conjunction with the Cleveland Clinic Foundation for Motion Analysis in the 1980's allows the gait researcher to place a three point marker triad on the shank and thigh segment of the child and adult. Its purpose is to assess the segment's rotational factors more precisely, especially in children with severe rotation of these segments. The data captured on the CC marker set is automatically tracked by the Motion Analysis: HiRES system and then the software OrthoTrak automatically takes the data and calculates joint kinetics and kinematics, Ankle, knee and hip forces, Varus/Valgus of the femur, tibia rotation... The Cleveland Clinic marker set was based using cadaevors and the research associated with cadaevor bone segments and mechanical properties of the segment, etc.

The Cleveland Clinic marker set requires a static trial of the left and right legs to automatically calculate joint center information for the lower body. The disadvantage of using the CC marker set with a non-Motion Analysis type of system is that the other systems (Vicon, Peak, Qualisys, Elite) cannot identify the triad markers and would see them as one large marker. (Maybe their systems have changed, but check your specific manufacturer for proven data). Hence defeating the purpose of placing a 3 point cluster in a plane parallel to the long axis of the bone to capture the motion. That is why all other systems use a Helen Hayes, Modified Helen Hayes or some aspect of a single point at the location marker set to calculate the motion. They have poor resolution on their system, secondly the CC requires an extra trial (static), therefore is it deemed extra work (5 minutes) for the technician (versus spending tens of minutes with a Knee Alignment device and its potential inaccuracies of misalignment) and thirdly, fewer markers on the segment tracks faster and may be deemed easier to edit with non-Motion Analysis systems. So accuracy was sacrificed for speed.

Now I do not see why you can not place three - 10mm sized markers on a small "t" shaped jig, but insure that your tracking software can track it and the reporting software can report it.

But the fact remains, the CC marker set provides a true 6 degree of freedom cluster at each of the four lower body segment takes less time than the KAD's technique, is more accurate for joint center calculations and can be tracked automatically and identified at no difference in time than the Hayes single point wand technique (well at least with our system). It has been used in Hundreds of Gait, sports, Rotational studies, Animation, Neuroscience, etc. investigations. It can also be used on the upper body too and processed with our KinTrak Software system.

I will ask my colleague at Motion Analysis Murali Kadaba, Ph.D, who heads up our Engineering/Biomechanics Research applications in Santa Rosa for a second opinion on the Cleveland Marker set and its use with Non-Motion Analysis systems. I do suspect the answer would be: the specific company or user would need to write specific software for the cluster, but first the system needs to see the extra 12 markers.

The Cleveland Clinic Marker Set is and always has featured upper body markers and now being expanded to the head too to assess head rotation, lean and tilt.

The original data and concurrent work on the Cleveland Clinic marker set has never been published and it will not be published. It is the main advantage of our system over all others: accuracy and precision. Like the best x-ray machine on the market, their data is kept under security to maintain their competitive edge over its competitors too.

It has been validated and continues to be validated by our hundreds on users worldwide.

Further discussions on this topic can be sent directly to me at the following coordinates.

Quick references:

<http://www.ivanhoe.com/docs/backissues/3dgaitanalysis.html>

<http://www.ivanhoe.com/docs/backissues/slippingstudy.html>

<http://www.ivanhoe.com/docs/backissues/lightscameraaction.html>

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Dan

I appreciate the high quality of the system which you are rightly proud of, but I would like to take you up on one point which you could possibly answer for me and that is in relation to the static test. It strikes me that if the subject cannot adopt the 'neutral' standing position for the static, then even your model will not be able to correctly define the anatomical axes accurately. We all have the same dilemma in that we are trying to estimate the position of underlying rigid bony segments from markers placed on surface tissue. All data produce from surface markers, on bony segments, is inferential - i.e we can never know that our markers actually reflect the true bone orientation/position. Different protocols have different advantages and disadvantages and yes, Prof Capozzo has demonstrated objectively that there are advantages to be gained from using clusters of markers. However the inferential nature of our results cannot be ignored - all we can ever do with our different approaches is to shuffle the pack, in terms of the sources of error. I really do not feel it is reasonable to claim that one approach is inherently superior to another.

regards

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To avoid commercial advertisement in a public forum, let me rephrase the statement, that in the past when such systems were going through development, and tracking of markers, resolution of cameras, and speed of processing etc. were time considerations, companies including Motion Analysis and all its competitors, Vicon, Elite, Peak, Qualysis, Ariel.....etc.. sought to provide the most meaningful 3D data to the technicians. Markers were large, systems were slow, camera resolution was not as it is today. And those are facts. Today, all vendors strive for excellence, we work hard to meet your performance needs and I am not seeking public criticism to my vendor colleagues and respect their systems and performances.

A second fact is that all motion capture companies developed technology to read a single marker at the femur and shank that was provided by researcher. One also developed a cluster based upon research. Hence, years ago tracking triads may have been difficult for motioncapture companies. Today it should be standard and a mute point.

Third fact is that today all such systems, and I'll refer to Dr. Jim Richards presentation at July 3rd, 1998 ISB 3D Comparison Symposium, can identify a cluster of markers, and if not have some intelligence to edit the unnamed or unidentified marker pathway. (I have copies of this report for those interested and will send.)

The Fourth Fact is that only one motion capture uses such a cluster today in its gait software and the others do not. Therefore if a cluster triad is used in a gait analysis, would the commercial software be able to generate the gait report and use the data? I can speculate that the users and commercial vendors are quite satisfied with their outcomes. I am aware of several commercial vendors developing cluster marker sets for the future and also further enhancing their technology. I can suspect with high level of confidence that Peak's Motus, Ariel's APAS, Qualisys 3D Program and Vicon's Body Builder can use cluster data to transform the information for kinematics and kinetic measurements. (January 98: Gait and Posture 7 (1998) 1-6 Holden and Stanhope identified a cluster of targets on the Femur and Shank to seek moment calculations. This was done with a Vicon system and Move 3D from NIH). Jeremy Linskill of Dundee Scotland reminded me that: "Different protocols have different advantages and disadvantages and yes, Prof Capozzo has demonstrated objectively that there are advantages to be gained from using clusters of markers. However the inferential nature of our results cannot be ignored - all we can ever do with our different approaches is to shuffle the pack, in terms of the sources of error". But my statement was to check it out and get proof.

So my point is before you start tossing extra markers on the segments to calculate joint centers or whatever, you need to understand your system's

limitations and capabilities to be altered and accept the data. Can you avoid static trials using medial and lateral markers at the knee and ankle, can you use KAD's or related devices? One research group takes a static series of pictures and manually digitizes the pictures with one system and sends that data into another system to create 3D joint centers and final reports.

Personally, I would rather see non-commercially funded researchers conducting such investigations. For your information, In Japan on July 3 and 4th, 1999 will be the 3rd motion capture 3D Comparison Meeting at which vendors have the ability in a public forum to have their system compared. Maybe this activity should be repeated, with what is scenarios, (what if I create virtual markers?, what if I add a cluster of markers?, what if the raw data is bad, how can I correct it)?

Sincerely,

Dan India
Motion Analysis Corp.

Chris,

I look forward to communicating with you more about this stuff. By the way, I have had issues with the way MAC's OrthoTrak 2.5 (1986-1995) calculated the helen hayes model without the use of any static capture or knee axis jig. This model's accuracy was completely dependant on how well you could align the thigh and shank wands to the flx/ext axis of the knee and ankle respectively. That's like trying to align a pencil to the side of a coke can. For this reason I went with the cleveland clinic set since we started our lab in 1991. Since Jim Richards, myself, Dr Freeman Miller and MAC got together and created OrthoTrak4.1 which has programmed into it a helen hayes model for use with static trials, my feeling about this model is much

better. Same exact model as in 2.5 except now the alignment of the wand has no bearing on accuracy because of the static trials for each leg. I am probably babbling on here because I am fading fast so I think I will catch up with you upon my return from the conference.

Anyway, have a great week.

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Dear subscribers,

First I would like to thanks those who answered my first question concernin Cleveland marker set. I would like to enlarge the debate concerning advantages and disadvantages of marker sets used for gait analysis. Looking in Biomch-1 archives I identified the four following marker sets :

- Helen Hayes marker set
- Ohio State University marker set
- Cleveland Clinic marker set
- Mayo Clinic marker set

I was unable to find informations concerning those marker sets on the web (I searched on the concerned Clinic's web sites and medline). I would be very grateful if our community could share knowledge and experience on this topic. I would like to know what are the differences between these marker sets and what are advantages and disadvantages. Many thanks by advance,
Stephane

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Talking about Marker Sets, I would like to include in the list the Cappozzo / Istituti Ortopedici Rizzoli marker set, supported by the following publications:

Position and orientation in space of bones during movement: anatomical frame definition and determination; A.Cappozzo, F.Catani, U.DellaCroce, A.Leardini; Clinical Biomechanics, Vol.10(4) 1995;171-178

Position and orientation in space of bones during movement: experimental artefact; A.Cappozzo, F.Catani, A.Leardini, M.G.Benedetti, U.Della Croce;Clinical Biomechanics, Vol.11(2) 1996; 90-100

Data management in gait analysis for clinical applications; M.G. Benedetti, F. Catani, A. Leardini, E. Pignotti, S. Giannini; Clinical Biomechanics, Vol.13(3) 1998; 204-215

Validation of a functional method for the estimation of hip joint centre location; A.Leardini, A. Cappozzo, F. Catani, S.Larsen, A. Petitto, V. Sforza, G. Cassanelli, S. Giannini; Journal of Biomechanics; 1999; 32(1): 99-103

Nice to talk to you all,

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You'll find the **source code for processing the cleveland clinic marker set** inside the distribution of **ANZ** on the biomechanics website. There are a lot of comments in there that explain how the markers need to be placed and how they are processed to compute 3d motion of the segments. I think there are also comments on what it can't do. I wrote the software about 10 years ago so I can't say what exactly is in there, but I know that we used it a number of times when I was post-docing at mayo clinic. We also put together some other modified versions of the marker set that are in the software also. I think you will also find references to literature explaining the marker set.

--dwright

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Hi Chris

Your last Biomch-L posting has me confused! You stated "the relative merits of the Davis versus Cleveland marker set". I understand the Cleveland Clinic marker set---I work at the Cleveland Clinic, and I know of the work done by Kevin Campbell prior to me moving to Cleveland. As an aside, none of the current gait-related work at the Cleveland Clinic uses the "Cleveland Clinic" marker set, although we do use a system we purchased from Motion Analysis Corp. I personally use the Helen Hayes system.

By "Davis", I'm assuming you are not referring to me! I did do some work with Kit Vaughan, and together we published a book that uses a marker set different from the Cleveland Clinic, Helen Hayes, and any other marker set that I know of. However, if anyone should get the credit for our marker set, it should be Kit, since he did 99% of the development. Peak Performance sells a gait system that is based on Kit's marker set, though this system has been expanded to use other marker sets too. I'm not exactly sure what Kit called his marker arrangement, but at one stage we called it the "Charlottesville, Cleveland, Cape Town (CCC)" system to reflect the fact that the three authors of the package were at that time in three different cities. (In contrast to both the Helen Hayes and Cleveland Clinic marker sets, the CCC system does not use triads or wands for marker placements. The CCC system places all the markers directly on to anatomical landmarks.)

Regards, [Brian](#)

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Dear Brian & Kit,

Now you've got ME confused too! I thought the VCM marker set was designed by ROY Davis!

Anyway, I'd be glad if Kit can clarify the whole business.

Chris

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[Dr. Chris Kirtley MD PhD](#)  
 Dept. of Rehabilitation Sciences  
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Dear Brian and Chris

Here's my take on all of this:

- (1) When I did a post-doc with Mike Whittle at the Oxford **Orthopaedic Engineering Centre** (OOEC) in 1983, I developed a 15 marker set. In fact, we gathered data on Ros Jefferson at that time and her data set is included in the package called **Gait Analysis Laboratory** which was published by Human Kinetics in 1992 (the software was written in 1988-89) where the

co-authors were Vaughan, **BRIAN Davis** and O'Connor. The marker set is illustrated in Figure 3.4 (page 23) in the book "Dynamics of Human Gait".

- (2) In the late 1980s, Murali Kadaba and colleagues at the **Helen Hayes Hospital** in upstate New York developed a 13 marker set. It was published in the Journal of Orthopaedic Research in 1990 (Volume 8, pp. 383-392). This set is sometimes expanded to 15 markers by the addition of markers on the heels. It is referred to as the Helen Hayes (Hospital) marker set and is essentially the same as the set used by the group at the Children's Hospital in Newington, Connecticut, where **ROY Davis** was the lead engineer. His main paper on their approach was published in Human Movement Science in 1991 (Volume 10, pp. 575-587). It is on these two papers that Oxford Metrics have based their VCM model. The marker set has never been referred to as the Davis set as far as I know.
- (3) In the mid- to late-1980s, **Kevin Campbell** was at the **Cleveland Clinic Foundation (CCF)**, and the CCF had just purchased a system from Motion Analysis Corporation (MAC). The CCF contracted to MAC and, with the clinician **Chet Tylkowski** from Florida, they developed their marker set and the OrthoTrak product. During my first few years at Virginia (1989-92), we had a MAC system and used the CCF marker set and I can tell you it was a pain in the butt! We switched over to the HHH marker set and, in time, to Vicon370 and VCM.
- (4) The Gait Analysis Laboratory package referred to in (1) above, will be released on CD-ROM shortly (yes, Brian, we are nearly there!) and it supports the 15 marker HHH system. Watch this space for an announcement, Chris!

Well, that's it from me. I hope you're now up to speed, Chris.  
Regards.

[Kit](#)

Having read all the discussion so far on the marker set issue, i.e CC vs. HH sets it strikes me that **2 issues are being merged into one here**. The 2 items appear to be the **benefit of clusters of markers** and the best method to obtain **reasonable estimation of femoral orientation**.

As far as I understand it, the benefit of clusters is in relation to the reduced susceptibility of their combined output to skin movement artefact, compared to single markers. The issue of why VCM uses the hip joint centre co-ordinates as one of the points to define the thigh segment is really a diversion.

The reason we developed the mirror technique was mainly because we did not like the idea of defining a bi-condylar axis relying on the medial condyle and the reason for this was that we felt that the **medial condyle was too vague an anatomical landmark** to rely upon - whether with KAD or 2 condylar markers or any other protocol - especially in a pathological knee. We feel much more comfortable using our clinical experience to identify and replicate sagittal plane knee motion.

I think separating the 2 issues out will allow us to gain more value from the discussions.

regards

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Firstly it would like to inform that my academic formation was not in the biomechanics area. I don't also possess specialization in this branch, therefore I would like to ask excuses for the primary level of my doubts.

Subject: Questions about the determination of flexion/extension axis of the knee for gait analysis (angles of flexion/extension, rotation and valgus/varus) with Vicon 370/VCM system.

I have used as reference the work of Mr. C. Frigo and Mr. M. Rabuffetti (Multifactorial Estimation of Knee Joint Centers for Clinical Applications of Gait Analysis, Gait and Posture 8 (1998) 91-102).

page 92:

"A different situation applies at the knee. The joint kinematics are determined by the geometry of the internal surfaces and by the restraining forces from muscles and ligaments [13]. A fixed centre of rotation does not exist. Theoretically, knee motion should be described using an instantaneous axis of rotation, whose position and orientation change in space ('helical axes of motion') [14-16]. However, this kinematic definition, that in some circumstances places the axis outside the body, does not relate readily to the concept of joint centre as used in clinical practice. Moreover, its

estimation can be affected by measurement errors."

To analyse the efficiency of KAD and possible methods for its substitution, I would like to know the opinion of the members of CGA about the following definitions:

Having the KAD the following finalities:

a) Determine the frontal thigh plane, from of 3 points: hip center calculated (equations of Davis, Öunpuu and Tyburski), axial and virtual markers of KAD.  
 b) In the frontal thigh plane determine the knee flexion axis, as well knee joint center, and the longitudinal axis of the thigh, being these two axis perpendiculars.

- Is there a definition for frontal thigh plane?  
 - If there is, could be this definition "translated" to a mathematical model?

- Would it be possible to create a definition of frontal plane - to thigh and leg - that could be specific to the movement studies (gait analysis)? To this finality, would it be possible to use any variables that could be collected by the Vicon System?

- May be the movement of flexion/extension of the knee considered always as predominant (much major magnitude) in relation with the movement of rotation and valgo/varus? If so, would it be possible to use this movement as reference to determine the sagittal thigh plane?

Thank you for your attention.

Best Regards,

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 Gait Laboratory  
 AACD - Brazil

I said I'd give you some **feedback from the VICON user meeting in Dallas** where I spoke on the problems of determining the knee axis. I've taken this opportunity of also copying this to CGA.

Several sorts of people seem to exist. First are those who don't realise there is a problem (these are, thankfully, very few and far between but they do exist). Second are those who recognise there is a problem but feel powerless to do anything about it (these are by far the majority). Third are those who recognise the problem but through sheer experience and attention to detail have learnt how to put the KADs on reliably (restricted in my conversations to one person!)

**Conclusion: that KADs can be used reliably if you put sufficient time and thought into learning how to use them.** The emphasis here must be on the thought. Those people that have mastered the KAD also have an in depth knowledge of what the consequences of poor KAD placement are and how to spot them in the gait data.

**One tip was to try and place the thigh wands accurately and the KADs accurately.** If both are successful then the Thigh Offset calculated from the static test will be small. If it is large then you must suspect something is wrong somewhere.

It was reinforced that this understanding is around. Murali Kadaba's original paper (Kadaba, M.P., Ramakrishnan, H.K. and Wootten, M.E., 1990. **Measurement of Lower Extremity Kinematics During Level Walking. Journal of Orthopaedic Research, 8, 383-392.**) went at some length into the consequences of poor definition of the knee rotation axis. Ed Cramp (eac@emgsrus.com) pointed out that Motion Lab Systems who market the KAD have a very **comprehensive manual** (since May 1998).

Perhaps the final word should go to that physio who had perfect confidence in her own methods "Its an art, not a science".

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