OA TECH+ NETWORK PLACEMENT REPORT

The impact of surgery to treat osteoarthritis on the surrounding joint assessed with gait and biomechanical analysis

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September 2021

Contents

Aim

To relate my understanding of the factors that cause cartilage wear in Osteoarthritis (OA) to the biomechanics of the OA patient

Objectives

1) To understand the history of biomechanics

2) To observe gait and rehabilitation activities in patients

Introduction to the scientific concepts relevant to the placement

Introductory discussions with Professor Philip Rowe highlighted the importance of the PhD research conducted by Professor John Paul, 1967, titled "Forces at the Human Hip Joint" [1].

It was founded from the research by John Paul a procedure to calculate the variation in hip joint force. Results identified a maximum joint force at toe-off directing upwards, whilst the next highest force was identified at heel strike also in the upwards direction [1]. The measurement of force was mentioned to be affected by speed, stride length and stature [1]. It was further stated in the work of John Paul the high-level complexity of the mathematical models, thus it was not possible to apply normal variation estimation methods. Alternative methods were used to measure the order of magnitude of such variations. This occurred systematically by varying the experimental quantities for frames per subject [1].

Further from Paul's research was the invention of the 'Paul Cycle' – used as the standard for testing implants for hip implant design [1]. Sine cameras used by Paul in 1967 were progressed to the use of analog TV cameras and finally through to the use of Charlie hip replacement [1].

The placement at the University of Strathclyde was an excellent opportunity to be a part of a variety of activities listed below:

- Discussions with Professor Philip Rowe on the history of biomechanics and novel developments for rehabilitation purposes at the University of Strathclyde. Further discussions with other department members of a similar research background for the exchange of ideas and knowledge

- Clinical session observations of live patient rehabilitation programmes

- Visit to clinical research facility at the Royal Infirmy Hospital (RFI)

Key methods/techniques observed

There were several techniques that I had the opportunity to observe during the placement at the University of Strathclyde. These are summarised below:

- **OpenSim**

OpenSim technology is defined as a "State-of-the-art simulation software advancing research in rehabilitation science" [2]. This mechanical based technology allows for modelling of surgery to assist with hand movement rehabilitation post spinal cord injury. OpenSim is also used to examine internal muscle strength such as during crouch gait or exercise [2].

- **Vicon Nexus (clinical purpose)**

Visual capture software cameras are used at the University of Strathclyde as shown in Fig.1. These are attached to the treadmill to capture specific points positioned with markers on the human body via infrared light (Fig.1). For analysis of a subject in a larger space i.e. amongst force plates, the cameras are identified in Fig.2 as green when activated. The focus on the Vicon cameras can be adjusted accordingly. The key benefit of the Vicon system is to reconstruct biomechanics in a 3-dimensional configuration. The steps below are implemented for surgical procedures:

- System turned on

- Set software running. This allows live software to stream out data to collect from the programme

- Set clusters to active – up to 21 maximum; cluster 21 used as the pointer

- Allocate clusters on anatomical sites via a drop-down function on the software

- Select on the region for the allocation; which cluster the site is allocated to

- Visualisation of the biomechanics in action

- C+ programming to calculate the model

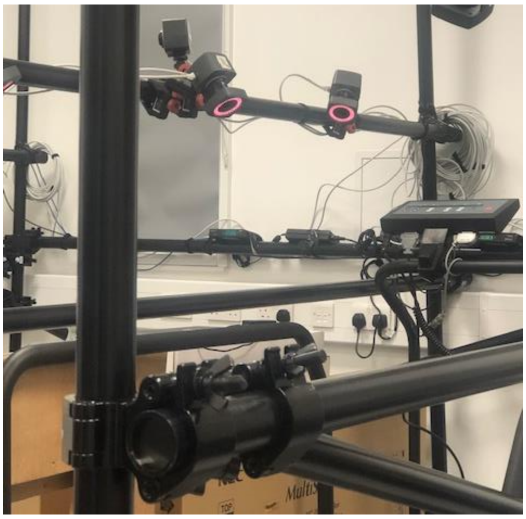

Figure 1: Attachment of Vicon Nexus visual capture software cameras to treadmill for gait analysis via markers positioned on the body. Image taken at the Biomedical Engineering department, University of Strathclyde

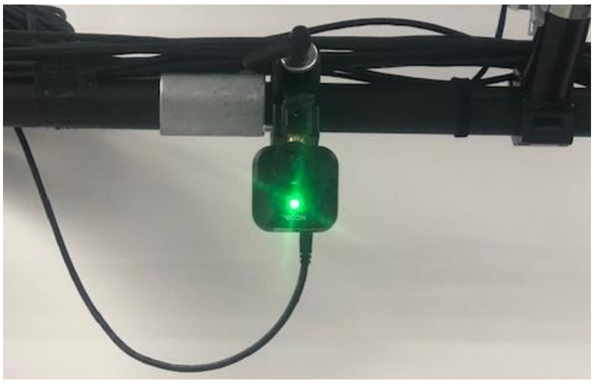

Figure 2: Confirmation of activated Vicon Nexus visual capture software cameras with green light on display. Image taken at the Biomedical Engineering department, University of Strathclyde

- **Torque measuring device**

Connected to an amplifier and strain gauge for measurements

- **Motion capture**

Defined as the recording of people movement used for gait analysis and robotics control [3]. To measure motion capture the schematic in Fig.3 displays an outline of a typical device which consists of recording points across differing axis.

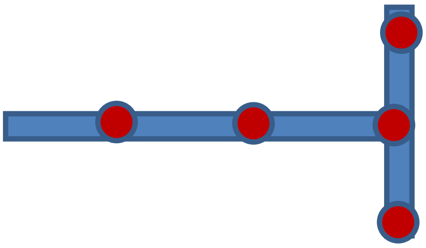

Figure 3: Schematic to display a motion capture device with red points to showcase the importance of recording points across differing axis, for the device to function correctly

- **Plug-in-Gait**

Plug-in-Gait is a technique that uses tracking markers to determine the position and direction of a segment. Markers for Plug-in-Gait should be placed at the following locations [4]:

- Upper Body (left and right front head, left and right back head, torso to include vertebrae, sternum, back as well as arm markers across shoulder, arm, elbow and wrist) [4].

- Lower Body (pelvis, leg to include knee, thigh, ankle, foot to include toe and heel) [4].

Following the set-up of markers on the various anatomical landmarks, manual labelling is used to assign on the system. Typically, the colour green refers to the right anatomical direction, red refers to the left and blue refers to the front. The subject area is entered e.g. using the knee width to calculate the centre of the knee. Plug-in-gait is widely used by clinicians for its effectiveness.

- **Mako Rio machine**

As sold by Stryker for robotic assisted surgery, the "Mako enables you to have a more predictable surgical experience when performing joint replacement surgery" [5]. Mako is used to target the damaged region of the surgical site on the knee or hip, enabling the surgeon to accurately insert the implant within the joint [6]. Advantages of Mako robotic machinery relate to the saving of surrounding healthy tissue and thus increased recovery rates [6]. The use of robotics for surgery is on the outlook to increase in the future.

- **Cluster technologies with Vicon software**

A light-up device as shown in Fig.4. The cluster is connected to 'Beacon', a radiofrequency transmitter receiver for configuration and is used to provide a 3-Dimensional orientation for the tracking of a segment.

Figure 4: Clusters with light-up regions identified with a blue colour and wires for the connection to a radiofrequency transmitter. Image taken at the Biomedical Engineering department, University of Strathclyde

- **Visual Studio**

This technology relates to setting up a cluster model of up to 21 clusters, where cluster 21 is used as the pointer cluster. Full body allocation of clusters is a total of 16 clusters. Initially, the location of where to place the cluster on the body is selected, followed by the anatomical land-markers to include. Finally, the regions on each anatomical landmark are selected. The segment locations identified with clusters can be used to measure angular velocity.

- **Nexus-biomechanics Tracker (animations)**

For this technology, initially calibration takes place via a wand to identify the camera locations. Following calibration, the wand is placed where the centre of origin should be.

- **Deflow**

Object orientated load/weight application linking to a games software e.g. a city with moving cars and the requirement to dodge the car by leaning weight on each side.

- **Training programme; hand/arm/gait activities for the rehabilitation of patients**

Similar training programmes were set-up at both the University of Strathclyde and Royal Infirmary Hospital (RFI).

The training programme was scheduled to last a total time of 70 minutes to include rest periods for the patient to recover in-between activities. The programme was divided into five key areas below:

1) Mirror Therapy – this activity focussed on hand rehabilitation via hand and wrist exercises to last for approximately 15 minutes

2) “Gripable”- this tool focussed on rehabilitation of wrist activities to include flexion, extension, pronation, supination, radial and ulnar. The tool was used for various games to work on each of these defined movements. Game examples include “Pixelate”, “Concierge/Plume” and “Window Sill”

3) Shapemaster – various machines to include seated cross-trainer and arm strengthening. This equipment is not like those present at the gym as the patient only follows the movement through which is powered by the machine itself. This allows for slow movement recovery.

4) Treadmill – virtual reality inspired walking activities within an Island as well as weight balancing games on one leg. The balancing exercise varied from standing with one leg in front of another and repeating with the opposite leg. Closing of the eyes was also incorporated into the balancing exercise – particularly used for the elderly. The treadmill settings can be altered to increase the walking speed, initiating at 2.5 Km/H. The increase of treadmill walking speed depends on patient comfort.

5) Virtual reality activity – the patient wears a virtual reality headset and observes a basketball game to control capturing and movement of the basketball with a marker controller. This allows for rehabilitation of movement across varied positions and weight loading.

Following completion of the entire training programme the patient is typically asked the following questions:

- Have you been well?
- Have you experienced any muscle or joint pain?
- Did you find anything difficult during the training programme?
- Did you feel any discomfort during the training programme?
- Did you particularly enjoy anything during the training programme?

The force plates shown in Fig.5 are present in both the main lab of the Department of Biomedical Engineering as well as the RFI Human Performance Lab. The force plates are used to measure the weight distribution of the patient, such as which leg and within which region of the leg carries the greatest weight.

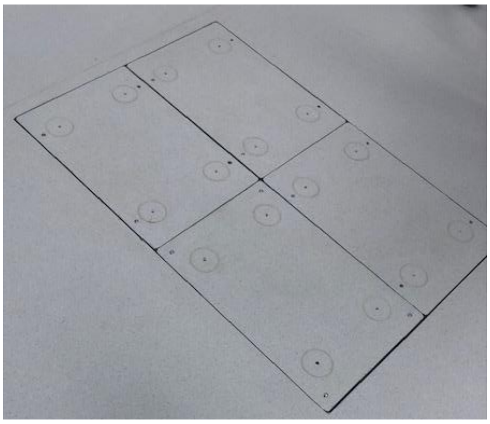

Figure 5: Force plates to record the weight distribution of patients when undergoing rehabilitation training programmes. Image taken at the Biomedical Engineering department, University of Strathclyde

Additional equipment present at the RFI rehabilitation training programme consisted of steps, ramps and beds for the patient to lie down and carry out leg stretches difficult to carry out whilst standing. The rehabilitation procedure following surgery initiated at the RFI for a period of three to six months. The later stages of rehabilitation take place at the University of Strathclyde with the entire rehabilitation process taking place over approximately one-year.

Key results/findings

It was highlighted that the department of biomedical engineering at the University of Strathclyde were the first to characterise poroelastic collagen hydrogels. Results identified a decrease in permeability to act as barriers to add to the resistance of fluid flow – thus working on the decline of water content to increase the collagen stiffness [7]. The results further identified a 58% increase in the stiffness of the meniscus, thus the mimicking of the function of proteoglycans should be considered for repair techniques [7].

The department had also identified the absence of the improvement in the stability of patients one-year post arthroplasty surgery [8]. This outcome links to my PhD research findings whereby the prevention of the need for surgery should be the focus for cartilage damage, exploring cartilage replacement biomaterials at the earlier stages.

On a further note of orthopaedic surgery, the department of Biomedical Engineering authored a research paper to assess the use of computer assisted orthopaedic surgery (CAOS), with less than 5% of surgeons adopting the technology [9]. Disadvantages of the use of CAOS have been identified as economically related or the lack of accuracy in movement and direction [9]. However, with future advancements in artificial intelligence and robotics there is scope for improvement to existing CAOS technologies [9].

Further discussions with department staff highlighted the importance of proteoglycans and collagen type 2 for cartilage biomaterial development. A common material used for cartilage biomaterial development in the literature is calcium alginate however this material was debated. This is mainly due to the non-porous nature and therefore prevention of cellular ingrowth, fluid-flow and blood supply – key components for healthy cartilage. A suggestion to further improve the current state of calcium alginate cartilage biomaterials is to 3D print alginate to create the porosity. Further work is then required to overcome the challenges associated with incorporating cells within scaffolds for cartilage repair.

Overall conclusions

In summary, placement discussions recognised the need to establish more of a link between the various stages of OA research. For example, my PhD research focused on the damage contributing factors to OA, whilst the work at the University of Strathclyde explored the impact and rehabilitation following surgery. Therefore, it is important to better understand the relationship between cartilage damage and cartilage biomechanics to aid with the repair at the earlier stages of disease progression.

With relation to the biomaterial development aspect of my PhD, discussions at the University of Strathclyde have highlighted the importance of advancing the manufacturing of biomaterials with innovative techniques such as 3D printing. Following the development of biomaterials with enhanced mechanical properties and porosity, the structures can then be tested amongst the novel material evaluation techniques established in my PhD.

Overall, an excellent opportunity to consider the ways my PhD research links with other departments to create further research questions to solve for knowledge increase in the field of OA.

Placement highlights

- The opportunity to present a seminar titled *"The development of replacement biomaterials for articular cartilage"* to the Department of Biomedical Engineering at the University of Strathclyde. This seminar was based on my PhD and the three journal papers which were derived from this.
  See below for the seminar advertisement:

- ***"****Dr Mahmood will deliver a presentation on her PhD research which focussed on various distinct and novel developments for the characterisation of the surface damage of articular cartilage, friction and replacement. The content will showcase the multi-factorial effect of loading frequency at 10 Hz in combination with an increase in bone mineral density on the resulting effect of cartilage damage. The presentation will also highlight the development of novel techniques to assess the frictional torque and coefficient of friction of articular cartilage. In the event of cartilage damage leading to the condition of osteoarthritis, such techniques form the baseline for comparisons with potential articular cartilage replacement materials for repair"*

- Engaging with other experts within the OA research arena and discussing the ways to further advance my PhD research

- Observing patients at live rehabilitation sessions within newly built state-of-the-art virtual reality facilities

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[3] Vicon. *What is Motion Capture? | What Can I Use Motion Capture For?*. [online] Available at: <https://www.vicon.com/about-us/what-is-motion-capture/.> [Accessed 16 October 2021].

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