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Future of minimally invasive surgery in temporomandibular joint pathology

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Abstract
Minimally invasive surgery (MIS) has experienced a surge in popularity over the past few decades. The main reason for this is the significant reduction of surgical trauma with the minimisation or even elimination of incisions. Temporomandibular joint pathology remains poorly understood and treatment is controversial. For this reason, application of MIS to temporomandibular joints (TMJ-MIS) could be an option for patients with failure of conservative management and where open treatment could be considered aggressive although TMJ-MIS itself is also considered controversial. In this paper, we will examine the different aspects of developing TMJ-MIS in the future: biology and diagnosis, diagnostic arthroscopy, surgical technique, knowledge and training, and different treatments.

Keywords: Temporomandibular joint, temporomandibular joint surgery, temporomandibular joint arthroscopy, minimally invasive surgery

INTRODUCTION

Minimally invasive surgery (MIS) has experienced a surge in popularity over the past few decades. For a number of operations - such as appendectomy, tubal ligation, cholecystectomy, gastric bypass, myomectomy and prostatectomy - more than 90% are now performed through MIS approaches. The main reason behind this paradigm shift is the significant reduction of trauma to the patient's body that results from the minimization or even elimination of surgical incisions. This reduction in physical trauma, in turn, leads to a number of additional benefits for the patient such as a lower incidence of complications, reduced pain, quicker recovery, shorter length of hospital stay, minimal cosmetic deformity, decreased psychological impact and overall improved quality of life. Choosing the MIS approach over open surgery however, also means embracing a series of potential disadvantages from the surgeon's perspective. These include limited operating spaces, lack of haptic feedback, loss of stereovision and depth perception, diminished hand-eye coordination, prolonged learning curves, extensive operative times and increased costs[1].

There are however, various different issues that characterize temporomandibular joints (TMJ) pathology including etiology and pathophysiology, controversies about appropriate treatment, and even more debate with regard to treatment through MIS[2].

In addition to joint replacement and internal fixation of fractures, arthroscopic surgery is regarded as one of the three greatest improvements in the treatment of patients with conditions affecting the musculoskeletal system during the twentieth century[3].

TMJ arthroscopy is the MIS approach to this joint. The future of TMJ-MIS could be examined through: biology and diagnosis, diagnostic arthroscopy, simplifying surgical technique, knowledge and training, treatments.

BIOLOGY AND DIAGNOSIS

The literature is lacking concerning the correlation between clinical symptoms and arthroscopic findings of TMJ pathology. For example, the relation of TMJ synovitis with pain is still controversial. While Murakami *et al.*[4] finds a weak relation, Holmlund and Axelsson[5] finds no association at all. The type of pathology however, can influence arthrosopic findings and some observed correlations. For example, if arthroscopic exploration is undertaken in patients with rheumatoid arthritis, correlation will indeed be found between pain and the degree of synovitis[6]. Sato *et al.*[7] though found a positive correlation between pain symptoms and the degree of synovitis and an inversely proportional relationship between mouth opening and adhesions. More studies on the interpretation of and relationship between symptoms and prognosis of patients with TMJ pathology are needed.

It is recognized that different chemical mediators may be involved in producing symptoms. In general, inflammatory cytokines are highly expressed in TMJs affected by synovitis[8]. Proteomics, which studies the entire set of proteins, such as inflammatory mediators that are produced or modified by an organism or system, will be important in rheumatoid disease and it has much to inform knowledge on TMJ pathology[9].

Another point for further discussion in the diagnosis of TMJ disorders would be the value of cone beam computerized tomography. Cone beam computerized tomography is not routine used but its sensitivity in the diagnosis of sclerosis and condylar changes, and its relationship with chondromalacia is higher compared to MRI[10].

Obviously, magnetic resonance imaging will be important for information about the different characteristics of the soft and hard tissues of the TMJ[11]. We believe that other radiological investigations that are more accessible, less expensive and less difficult to interpret than magnetic resonance imaging should be considered. For example, high-resolution ultrasound enables dynamic examination which can aid in making clinical decisions but it is highly operator dependent[12,13].

Although we have gained some insight into the relationship between clinical symptoms, radiological findings and arthroscopic lesions, more universal and affordable diagnostic tools are required for TMJ pathology.

DIAGNOSTIC ARTHROSCOPY

When exploring the TMJ, we cannot forget to explore both the superior and inferior joint spaces. Liedberg *et al.*[14] evaluated the diagnostic accuracy of upper compartment arthroscopy of the TMJ. An arthroscopic diagnosis of pathological changes seems to be reliable (high specificity), but normal findings include a substantial risk of under-diagnosing pathology (low sensitivity). Tzanidakis *et al.*[15] studied arthroscopy and surgery 6 months post-arthroscopy. Overall, arthroscopy had 87% sensitivity and 99% specificity in diagnosing diseases of the TMJ. In summary, the specificity of arthroscopy is higher than its sensitivity since normal findings on arthroscopy include a substantial risk of under-diagnosis.

Inexperienced or novice TMJ surgeons tend to enter the inferior articular space accidentally. Classically, it is considered inadvisable to enter this space due to potential damage to the cartilage of the mandibular condyle. At this location, there may be pathological findings such as synovitis or adhesions. Since jaw opening consists of pure rotation of the condyle over the disk, persistence of symptoms in patients treated with TMJ arthroscopy may be the result of misdiagnosis with untreated adhesions and synovitis within the inferior joint compartment[16].

Besides arthroscopy, it would be very useful if other methods can aid in the analysis of surfaces or subsurfaces of the tissues involved in TMJ pathology. Ultrasound was performed on human cadavers, in combination with traditional TMJ arthroscopy. During these investigations, the main articular structures were identified: the glenoid fossa of the temporal bone, articular disc, mandibular condyle, and retrodiscal tissue. The combination of arthroscopy and ultrasound imaging provides more information on the position, movement, and pathological changes in joint structures of the TMJ[17].

Bioelectrical impedance analysis is an easy-to-use, non-invasive method that measures the electrical properties of the patient's tissues. Classic bioimpedance devices like body composition analyzers are commercially available on the market. In recent years, many new applications are finding their way into medical practice[18,19]. In future, this method could be used through the arthroscope to assess the different characteristics of tissues in both compartments of the TMJ.

Standard light provides a poor contrast between the collagenous joint structures (as they all appear off-white). Additionally, degeneration of joint structures further hampers the contrast and visualization. Collagen though, is an autofluorescent tissue component which can emit blue/green light (emission 400-405 nm) after excitation with violet/blue light (at 325 nm). This autofluorescence property is already in use by Orthopedics in other joints such as the shoulder[20] and could be applied to TMJ arthroscopy.

We need devices that can accurately evaluate all the tissues and compartments of the TMJ to assist us in decision making.

SIMPLIFYING SURGICAL TECHNIQUE

In most modern setups, high-resolution CCD cameras are used instead to transmit a live video stream to a flat screen. One of the main problems associated with video-assisted MIS is the loss of stereopsis i.e. perception of depth and three-dimensionality. This occurs when a three-dimensional (3D) image is projected on a two-dimensional screen, and is often the cause of impeded hand-eye coordination and erroneous movements of tools. The use of 3D technology in a small joint such as the TMJ would not be useful at this time because the advantages of this technique are clearer in larger joints.

Therefore, hip arthroscopy has an exploratory role in the treatment of undiagnosed hip or groin pain. Therapeutically, there are now many indications for hip arthroscopy including the removal of loose bodies, trochanteric bursitis and fpr femoroacetabular impingement. Recent navigation systems in hip arthroscopy also offer drastic improvements in the way of information[21]. For instance, navigation or computer-assisted TMJ arthroscopy can provide the surgeon with continuously updated information about the puncture sites and the location of instruments in relation to target and critical structures[22]. For a joint such as the TMJ however, "using a sledge-hammer to crack a nut" would seem more appropriate.

With regard to the approach of inserting the second cannula, there are several possible ways. We prefer the simple geometric principle of triangulation. After diagnostic arthroscopy has been completed, the other cannula can be inserted with a sharp and blunt obturator in an anterolateral point and medial direction. Two problems make this technique very difficult: the two compartments of the TMJ are separated by the articular disc, and the articular eminence. In future, computer assisted surgery could be useful in providing augmented reality, an "image-enhanced operating environment". It can be created by overlaying of a visual representation of the subsurface anatomy and critical structures, while integrating it with the video feed from the camera[23]. Augmented reality could be useful in different approaches to the TMJ although experimental and cadaver studies have been published. Wang *et al.*[24] presented a system, in cadavers, to provide augmented reality visualization during TMJ arthrocentesis to increase the precision of skin punctures.

Another point to be developed could be different instruments or technologies for use inside of the TMJ. Once inside the joint, the size of the tools needs to be minimized (to ablate tissue, seal vessels and cauterize). Many years ago, based on the effects of electricity, we developed mono- and bipolar cautery[25], excellent tools but without clear visualization and have important effects on surrounding tissues to coagulate and cut. Some years ago, radiofrequency emerged with less thermal damage to surrounding tissues, no smoke or bubbling, and greater treatment accuracy[26] and we now have the plasma sprayer system for surgeries. Plasma is composed of highly ionized particles. These ionized particles separate molecules from each other and reduce tissue volume. It will not damage tissues directly and cause little damage to surrounding healthy tissues[27]. It could be key for the next step required in arthroscopy - resection. Sometimes, lasers are also used for ablating tissues but it is, and will be expensive with no real advantages otherwise.

Another fertile area of research in surgical robotics is the application of machine learning algorithms for the creation of human-robot cooperative control frameworks in which the surgeon is aided by the machine in the most critical parts of a task. Using a double console setup can thus be beneficial for training and learning purposes, both for the novice and the machine: as expert surgeons perform a physical or virtual surgical simulation, trainees can follow their steps using another machine, while the robot can track the instruments, implementing complex algorithms in order to improve performance. The surgical community is still focused on the question of 'robotics' in surgery. To be clear, the term "robot" is completely inadequate to describe a da Vinci: telemanipulation systems'. In robotic-assisted surgery, the instruments are not moved directly by the surgeon as he operates through master controls, which improves the surgeon's dexterity and skillfulness leading to ultraprecision with no tremors at all. The advantages though seem to be clinically significant only in a subset of surgical procedures, such as rectal resection, abdominal surgery, cardiac surgery or some ENT procedures. It is important to understand however, that because of the size of the hardware, its use is limited in joints and even less in the TMJ. A major area of focus in the development of surgical robotic platforms is the implementation of haptic feedback. Haptics include sensations such as force, pressure, temperature and texture - all qualities that are difficult to quantify and represent in robotic and MIS procedures. It is hence a challenge for the surgeon to judge the right amount of force to apply and to make decisions based on tactile palpation. Another major challenge is the cost with economic analyses demonstrating cost-effectiveness only for high-volume centers[28,29]. In other words, robotics is far from being used in TMJ.

KNOWLEDGE AND TRAINING

The therapeutic results of TMJ-MIS could be related to patient selection, choice of technique and quality of MIS-arthroscopy but there is a high initial learning curve in MIS.

Traditionally, surgeons have acquired their skills by operating on patients under supervision with gradual independence (the so-called apprentice system or Halsted model). This method consists of "observing, practicing, and teaching". Whereas some open surgical skills may be innate, which develop naturally because of lifelong experiences with basic tools and utensils, the skills needed to perform arthroscopy are not naturally derived, and compared to open surgery, arthroscopy requires specific operative skills. For example, arthroscopy requires surgeons to perceive a three-dimensional environment from a two-dimensional camera image. Furthermore, specific hand-eye coordination is required, and the sense of touch is minimal. Finally, every endoscopic procedure poses the challenge of the fulcrum effect, such that when the surgeon moves his hand to the right, the working end of the instrument moves to the left on the monitor and vice versa. The surgeon has to actively compensate for this effect.

Cadaver studies continue to be the gold standard due to close resemblance with real patients. However, there are certain drawbacks, such as the high costs, legal requirements, lack of reusability, failure to reproduce different pathologies, and numerous political, cultural, and religious considerations. While surgeons have to learn from their mistakes, overcoming the learning curve should preferably be done outside of the surgical room.

Different simulators could be used: (1) box trainers are devices where trainees have to perform tasks using real instruments in a box while watching their movements on a video screen. They are relatively cheap compared to more advanced simulation models and the instruments used are the same as those in the operating environment. The disadvantages are they lack realistic features and the tasks do not sufficiently resemble those in real-life; (2) realistic simulators by recreating actual scenarios. The first prototype of a physical simulator designed for training in TMJ arthroscopy was presented. It was constructed according to anthropometric standards using a material that reproduces the different textures and colors of all anatomical parts. One of the advantages provided by the use of simulators is the possibility of repeating the exercise (reusability) as many times as needed to acquire the basic skills necessary[31]; and (3) virtual reality (VR) trainers are computer-based applications that allow for movement in free space whilst performing tasks in a virtual operative environment. VR can be combined with a physical model as an "overlay", hence they are often referred to as augmented reality trainers. These types of simulators offer the advantages of both systems, namely haptic feedback, real-life surgical material, realistic internal views, and training of different scenarios. For training in arthroscopic skills, knee and shoulder arthroscopy simulators based on VR are of interest[32].

TREATMENT

MIS is composed of three achievements: diagnosis, surgical resection and reconstruction. Different methods of suturing have been described[33-36] and a number of techniques have been devised for this purpose. Independent of clinical results, there does not seem to be any evidence that surgically repositioning a disc maintains it in a normal position in all cases. We must therefore be cautious when introducing new operative arthroscopic procedures that at best, may provide only marginal benefit over simple lavage and in the worst case, cause more surgical trauma. A successful surgery for the surgeon is not always a successful surgery for the patient. Complicated arthroscopic disc repositioning and suturing might not be considered routine.

Nowadays, mesenchymal stem cells could be considered as the latest "research trend" in the field of biology and medicine and their application in regenerative medicine is growing. Some modalities involve direct implantation of mesenchymal stem cells into the defect site while others use scaffolds to support the cells[37,38]. Vapniarsky *et al.*[39] approached anatomic defects by using scaffold free tissue engineering as an approach for the regeneration of TMJ discs to address disc thinning in the pathogenesis of TMJ degeneration. Treatment of these conditions that are prevalent in TMJ pathologies are palliative and not reparative. To address this, scaffold-free tissue-engineered implants were created using allogeneic, passaged costal chondrocytes. A combination of compressive and bioactive stimulation regimens produced implants with mechanical properties akin to those of the native disc. The efficacy in repairing disc thinning was examined in mini pigs. Compared to empty controls, treatment with tissue-engineered implants restored disc integrity.

The healing capacity of bone marrow mesenchymal stem cells (BMMSCs) has been evaluated in various studies but one study aimed to evaluate the effect of BMMSCs on the healing of TMJs with induced rheumatoid arthritis. Rats were treated by intravenous injection of BMMSCs. The results indicate that the treatment of induced rheumatoid arthritis with BMMSCs shows promise that need to be further investigated in humans[40]. Thus, the future could be regenerative medicine through tissue engineering in minimally invasive arthroscopy for TMJ pathology.

CONCLUSION

More studies are needed to interpret the relationship between clinical symptoms and the prognosis in patients with TMJ articular pain. More affordable and universal diagnostic tools are required for use in this pathology. An arthroscopic diagnosis of normality includes a substantial risk of under diagnosis of pathologic changes. We need devices that can accurately diagnose all the tissues and compartments of the TMJ to assist us in the decision making process. New technologies such as navigation and robotics are likely unsuitable for TMJ; however, augmented reality may be of use to develop best techniques. In relation to the steep learning curve in MIS, cadavers continue to be the gold standard but realistic virtual simulation would be the most logical evolution in the training of TMJ-MIS. The future of TMJ-MIS may be through regenerative medicine approaches such as tissue engineering.

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Authors' contributions

The author contributed solely to the article.

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Consent for publication

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