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Review article

The instability of wrist joint and total wrist replacement

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ABSTRACT

Total wrist arthroplasty are not used as widely as total knee and hip replacement. The functional hands are requiring surgeons to design a durable and functional satisfying prosthesis. This article will list the main reasons that cause the failure of the prosthesis. Some remarkable and representative prostheses are listed to show the development of total wrist prosthesis and their individual special innovations to fix the problems. And the second part we will discuss the part that biomechanical elements act in the total wrist replacement (TWA). Summarize and find out what the real problem is and how we can find a way to fix it.

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Background

With a history that over one hundred years, total wrist replacement (TWR) has been dug a thin way out blood and fire by generations of orthopedic surgeons. Yet still unlike other total joint replacement, the use of wrist arthroplasty has made slow progress within the orthopedic arena, remaining relatively uncommon.¹ The complexity of wrist joint anatomy, biomechanics and complications after surgery, which all dampening the initial enthusiasm on searching a perfect design of the prosthesis, made surgeons cave to the reigning of the fusion, after all the wrist arthrodesis has proven to be the most successful.^{2–10} The instability of the wrist after the total wrist replacement is the No. 1 killer of every prosthesis. Making a big breakthrough needs to take all into consideration that the instability factors that led to the failure which happened to former designs.

Wrist is a very flexible and most complicated joint, which helps us with very fine motor activities that require every muscle and soft tissues to cooperate with each other. Easily the arthritis, a common problem seen secondary to previous trauma, rheumatoid arthritis, or osteoarthritic degenerative changes in the general population, is

creeping up on it, breaking the perfect machinery and the balance.¹¹ Rheumatoid arthritis (RA) is the top one on the list which severely damage the wrist joint, and today also is the primary indication for the TWR.^{1,10,12} But for the radiocarpal arthritis, the fusion remains the first choice of the majority of hand surgeons.² While considering the RA patients usually with multiple joints involved, fusion may lead to a greater impairment and disability.^{1,2,11,12} Total wrist arthroplasty (TWA) can help to rebuild the system and balance, which provides motion, strength, and the stability needed to perform activities of daily living.¹³

Wrist prosthesis

Retrospecting the wrist prosthesis in the past decades, instability is the main complication in total wrist replacement which caused by dislocation, deviation and loosening, related to surgical technique and progression of disease.¹ Surgical challenges include centring of the prosthesis, fixation of the prosthesis, and soft-tissue balancing.^{1,14} So aiming at solving the problem, every prosthesis loaded the new thoughts of the designers and has salient features individually. Improvements in design constitute reconstruction of the centre of rotation and recreating the carpal height.¹²

Meuli wrist prosthesis

To adjust for problems with stability and imbalance, the Meuli 3rd generation prosthesis (MWP III) was released in 1986.¹ The

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prosthesis was made from a titanium alloy with a corundum rough-blasted surface for implantation using either a cement or press-fit technique.¹ The nitride coated ball was fixed to the proximal component and articulated with a relatively deep UHMWPE (ultra-high molecular weight polyethylene) socket distally.¹ The anchoring prongs of the carpal component were angled 15° dorsal to the median axis.^{1,15} The revision rate demonstrated a number of 26% and component loosening cited as the most common complication.^{16–18}

Volz prosthesis

In an effort to decrease the incidence of ulnar deviation, the design was modified to a single-pronged distal component in 1977.¹ But after several long time follow up, the instability was still a previously noted complication. In 1988, the original Volz prosthesis was redesigned.^{1,19} The new Clayton–Ferlic–Volz (CFV) device was a modular titanium prosthesis with an elliptical articular surface offset to facilitate wrist balance.^{1,20,21}

Trispherical prosthesis

The trispherical prosthesis includes a cemented carpal component with one long and one short stem inserted into the second and third metacarpals, respectively.²² The cemented radial component and spherical head make contact with the carpal component, creating an axle constraint through the articulation to prevent dislocation.^{16,22}

Guepar prosthesis

In an attempt to address the problem of distal component loosening the carpal component was anchored into the second and third metacarpal, using screw fixation.^{1,22,23} The GUEPAR prosthesis was the first to use a minimally constrained elliptical geometry to mimic the radiocarpal articulation.^{1,21}

Biaxial prosthesis

For this prosthesis the instability is still the main concern.¹² The distal component was created with a long, porous-coated stem for metacarpal fixation and an ellipsoid shaped head.¹ Porous coating has been applied to enhance bony ingrowth and fixation.²⁴ It aims to achieve physiological movement by offsetting the radial component ulnar-wards and volar-wards, bringing the third metacarpal into line with the ulnar border of the radius with the axis of movement passing through the centre of rotation, the proximal pole of the capitate.²⁴ The polyethylene bearing surface is attached to the porous-coated radial component.¹ Due to the significant concern of loosening in patients with poor bone stock, a custom multi-pronged distal component was designed.^{1,25} The distal component was modified to include a longer third metacarpal stem to bypass the weakened bone and an additional stem component to obtain fixation in the second metacarpal.^{1,26}

Menon prosthesis

Menon prosthesis also named as Universal Wrist Implant. The concave articular surface of the radial component has 20° inclination similar to the articular surface of the radius which is a Y-shaped titanium component that can be inserted with or without the use of cement.^{1,2,16} The distal component is a titanium oval plate that has three screw holes for augmenting the fixation to the carpus.^{1,2,16,27,28} A toroid-shaped, convex polyethylene insert locking over the carpal plate and articulating with the concave proximal

component, provides a functional range of motion and yet resist imbalance and instability.^{16,27–30} The surgical technique is designed to enhance the stability of the prosthesis. The carpal osteotomy is performed in the plane perpendicular to the axis of the capitate–metacarpal complex which minimal resection of the proximal end of the capitate.^{1,2,27,28} The solid intercarpal fusion provides broad support for the component.^{1,2,27,28} The radial component is cut parallel to the existing articular surface.¹ This prevents an increase in lever arm advantage for wrist flexor and ulnar deviators, leading to fewer problems with soft tissue balancing.^{1,29}

To improve the durability of the prosthesis, the universal II made some modifications based on the origin design. The inclination of the radial component has been reduced to 14° with material changed from titanium to cobalt chrome.^{1,16} Utility of beaded porous coat for bony ingrowth rather than cement would be preferable for both components to improve durability and reduce bone destruction if revision becomes necessary.^{1,4,16,27,28} The shape of the carpal plate changed to ellipsoidal fixed by two titanium screws and a central stem, and the size of the radial component has been widened.^{1,16,30,31} All above are designed to improve the stability.

The RE-MOTION Total Wrist System, designer focused on improving the motion of the prosthesis, allows 10° of rotation between the rounded peg on the carpal plate and the polyethylene ball that may provide the intercarpal pronation and supination and dampen torque which the universal II disabled, thus reducing the risk of implant loosening.^{16,32}

Biomechanical analysis

The centre of the prosthesis is proved to be the most difficult task to identify surgically.¹ Now the orthopedic, who have realized the difficulties and importance, are trying their best to design or fix the prosthesis to mimic the centre of the rotation of normal wrist. The centre of the rotation is the key to the stability of the prosthesis and the balance of the soft tissue. Meanwhile, we often ignore the important role that the soft tissue plays in the TWA. M. N. Bajuri et al. have done a study conducted to analyze the biomechanics of wrist arthroplasty using recently reported implants that had shown results with the aim of providing some insights for the future development of wrist implants.³³ The main point of their research is the RA, the disease itself, causing the pathological process progression of the wrist which also leads to the failure of TWA. The general three pathological changes are cartilage destruction, synovial proliferation and ligamentous laxity.^{33,34} The abnormal changes will bring the high contact pressure, high-stress concentration which leads to the tendon rupture and altering physiological bone translation and displacement.^{33–35} The RA wrists lose the balance of the biomechanics which result in visible deformity of the wrists.^{33,36}

The innovation of the prosthesis is very important as we formally committed, such as the RE-MOTION prosthesis has already done a great job in developing to resolve this issue while ensuring good joint stability.³³ However, the assessment of changes in the biomechanical forces acting to the wrist joint following TWA in rheumatoid patients appears to be paucity.³³ The study of M. N. Bajuri et al. was performed to analyze the changes in the biomechanical force of severe rheumatoid wrist after TWA.

The measurements included the stress distribution and contact stresses in severe rheumatoid wrist after TWA by assessing and comparing the load transfer throughout the joint and contact pressure at the articulations.³³ Their study constructed the RA model and healthy wrist model as control groups comparing to the TWA. The results of the bone stress distribution at the carpal complex showed that the TWA model with uniform load

transmission which means the stress transmission concentrated on a certain element, and the variations of stress magnitude were small. The stress transmission of healthy wrist was non-uniform and quiet even on every element with high magnitude of stress, as well as the RA model but lower magnitude. The RA disease caused the contact pressure ten times higher than the healthy wrist. After the TWA, the pressure reduced to five times which is almost similar to the healthy model.³³ And the most critical pressure loaded bone turned out to be the trapezium (excluding the resected scaphoid) in three models, especially in the RA case.³³ The high bone graft modulus had a positive impact on the load transmission efficient, the bones' stability and contact pressure reduced.³³ The load transmission at the radiocarpal joint transferred distally more to the scaphoid (63%) than the lunate.^{33,37} The overall load was transferred mostly to the radial side (63%).^{33,38,39} High contact pressure with stress concentration was due to the absence of cartilage and the eroded bone surfaces with the existence of sharp edges, and both of the pathological changes degenerating from the RA disease.^{33,34} The RA disease also caused the ligamentous laxity which couldn't help dislocating the carpus towards ulnar resulted in imbalance load transmission which also caused by the hand scoliosis condition.^{33,34}

Conclusion

Yet we can conclude that the effect of high contact pressure and imbalance load transmission which caused by RA are vital to be conquered.³³ The RE-MOTION implant solved the problems by intercarpal fusion and distal radius resurfacing, which confirmed to be a real good job on reducing high contact pressure and changing the pattern of stress distributions to uniform.^{32,33} The intercarpal fusion achieve by the bone graft with a modulus of 5 GPa produced more encouraging results in terms of uniform load transmission and lower contact pressure.^{33–40}

We are doomed to reinvent the wheel. There are always some spaces for us to improve. Make a good use of the biomechanical forces analysis we can improve our design more complied to anatomic structure. The components of the prosthesis can be designed fixed to the bone more solid which can reduce the loosening and enhance the stability of the prosthesis.

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