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Role of UHMWPE in Knee Transplant

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ABSTRACT — Tibial Insert, a plastic layer between the femoral and tibial plate plays an important role in the functioning of knee. Femoral slides on the tibial insert whenever the knee is bent or straightened or in action. As the femoral is a metallic component, the tibial insert should provide less friction. And also considering the objective of minimising the wear rate of the knee transplant, tibial insert is made up of biocompatible material. Ultra high molecular weight polyethylene (UHMWPE) is a very tough material with highest impact strength of any thermoplastic presently made and is finding wide applications in every field including automobile industries, bottling sectors and medical field. The properties of UHMWPE is favouring to be used in medical devices as it is self-lubricating with less coefficient of friction and minimal moisture absorption. The formation of UHMWPE and processing should be carried out with utmost care as the method of producing has direct impact on the wear. The recommended grade of UHMWPE required for medical and manufacturing method of tibial insert is justified.

KEYWORDS **-** UHMWPE, Tibial insert, Knee Transplant.

I. INTRODUCTION

Anthroplasty is a field of medicine which deals with surgical reconstructions and total replacements of degenerated joints. Knee anthroplasty is modern surgical procedure that can be accurately described as knee resurfacing. This procedure entails restoring the weight bearing facade of the knee joint that is damaged, worn out or diseased to relieve pain and movement disability. It is performed through the implant of an orthopaedic metal and plastic component shaped as a joint so that the knee can move properly. Researches have been done and the combination of metal–plastic –metal in total knee transplant for femoral- tibial insert- tibial plate respectively gives excellent result in terms of life. Over three decades UHMWPE is most widely used material for tibial insert. The structure of UHMWPE is a crossed linked intermolecular long chain which distributes load evenly resulting in strongest material with highest impact strength.

II. LITERATURE SURVEY

The two most widely used standards for medical grade UHMWPE are ASTMF-648 & ISO 5834. None of the existing standards for medical grade UHMWPE material properties are originally conceived from polymers that are subjected to sterilisation, irradiation or other processing techniques. These three steps are necessary to produce highly cross linked polyethylene (HXLPE) for hip and knee joint bearings. Heating above the melting temperature destroys the crystalline

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region and the disadvantage of melting reduces the crystal size, yield and ultimate strength. The solution arrived for this problem is to heat the material below the melting temperature which will retain the original crystal structure and mechanical properties [1]. But when machining the material several precautions are necessary. Several factors can be responsible for damaging UHMWPE through different feed rate, cutting speed of tool, spindle speed and accumulation of heat etc...When the material wears, it leads to mechanical failure and importantly biological wear. The debris that breaks off can react with tissue surrounding the bone. This reaction leads to loosening of the prosthesis and eventually replacement [2]. Though laboratory and clinical researches are limited, using HXLPE for hip replacement for youngsters are recommended but the for Knee replacement using HXLPE does not give satisfactory result [3]. On analysis of surface finish based on cutting speed and feed rate in some cases the surface roughness was high with cracks and in some cases there were undesirable feed marks. Upon experiments with various machining parameters the results shows that the surface roughness can be achieved when using the same parameters similar to the material aluminium and wood [4].

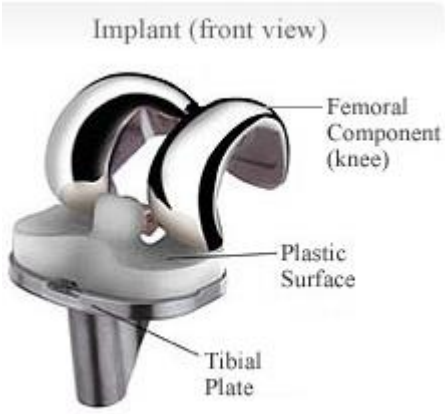

Fig 1. Anatomy of Knee Transplant

III. UHMWPE IN KNEE TRANSPLANT OR PROSTHESIS

The femoral and tibial component is made up of metals like titanium and it alloys or cobalt – chromium or tantalum. The tibial insert which is one of the important components of the knee implant, attached and mounted on the tibial tray that provides smooth movement of other components against it and also wears out minimally. In many cases, it replaces the worn out cartilage meniscus present in between the femur and tibia. Tibial insert is fabricated using biocompatible biomaterials according to standards. Usually ultra-high molecular-weight polyethylene (UHMWPE) is used. UHMWPE continues to find increasing in industrial applications, including the automotive and bottling sectors, total joint arthroplasty in orthopedic and spine implants, ballistic protection, defense applications and medical devices, textile, chemical processing, paper & pulp, maritime, mining, sewage treatment, bulk material handling and agriculture industry. UHMWPE is a subset of thermoplastic polyethylene. It is also known as high-modulus polyethylene (HMPE) or high performance polyethylene (HPPE). It has extremely long chains, with a molecular mass usually between 2 and 6 million u (Unified atomic mass unit, $1u= 1.66054X10^{-27}$). The longer chain serves to transfer load more effectively to the polymer by strengthening intermolecular interactions. This result in a very tough material, with the highest impact strength of any thermoplastic presently made.

The major functions of the tibial insert include;

- Provide less friction between mating components and hence leading to minimal wear
- As a substitute for the meniscus in case it is absent
- Provide smooth movement between the rubbing components
- Ease of bending and straightening of the knee

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- Extend the life of the knee implant.

IV. PROPERTIES OF UHMWPE.

- Highly resistant to corrosive chemicals except oxidizing acids
- Very low moisture absorption
- Very low coefficient of friction
- Self-lubricating
- Very tough material with highest impact strength
- Very resistant to water, moisture, most chemicals, UV radiation, and micro-organisms.

Properties	Units	Specification
Density	gm/cm^3	0.925 - 0.945
Water absorption	%	Nil

Table 2. Physical Properties of UHMWPE

(Source: Hand Book of UHMWPE)

Properties	Units	Specification
Melting temperature	Degree Celsius	130 - 136
Coefficient of linear expansion	k^{-1}	$1x\ 10^{-4}$

Table 3. Thermal Properties of UHMWPE

(Source: Hand Book of UHMWPE)

Properties	Units	Specification
Tensile strength at yield	MPa	19.3 - 23
Ultimate tensile strength	MPa	30.4 – 48.6
Elongation at break	%	200-350
Hardness	Hrc	62-66
Abrasion resistant	%	100
Izod impact strength	KJ/m^2	>25

Table 4. Mechanical Properties of UHMWPE

(Source: Hand Book of UHMWPE)

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Chemicals	UHMWPE	Poly Propylene	Polyacetal	Teflon	Nylon
Water	+	+	+	+	+
Acid	+	+	-	+	-
Lye	+	+	+	+	+
Hydrochloric acid	+	+	+	+	+
Oils / Fats	+	+	+	+	(+)
Alcohols	+	(+)	(+)	+	
Easter	+	(+)	(+)	+	(+)
Organic acid	(+)	-	(+)	+	(+)

Table 5. Chemical Resistance of UHMWE Product in Comparison with Other Plastics

V. COMPARISON OF UHMWPE WITH OTHER MATERIALS

Abrasion Resistance

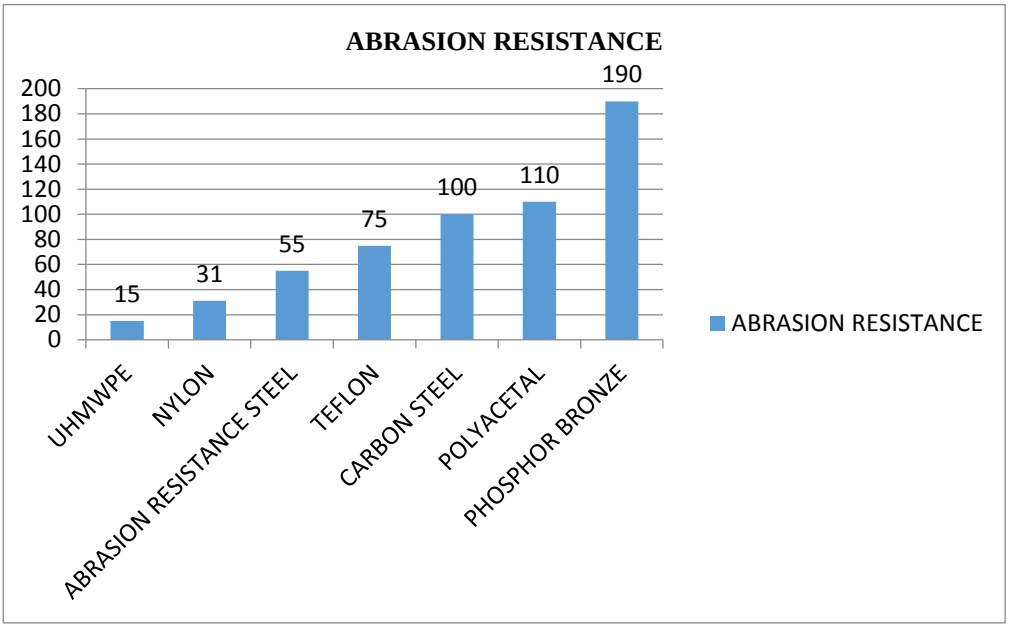

Fig 2. Graph of Comparison of Abrasion Resistance of UHMWPE

(Source: Hand Book of UHMWPE, Biorad Medisys Pvt Ltd, Pune)

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Notched Impact Strength Values

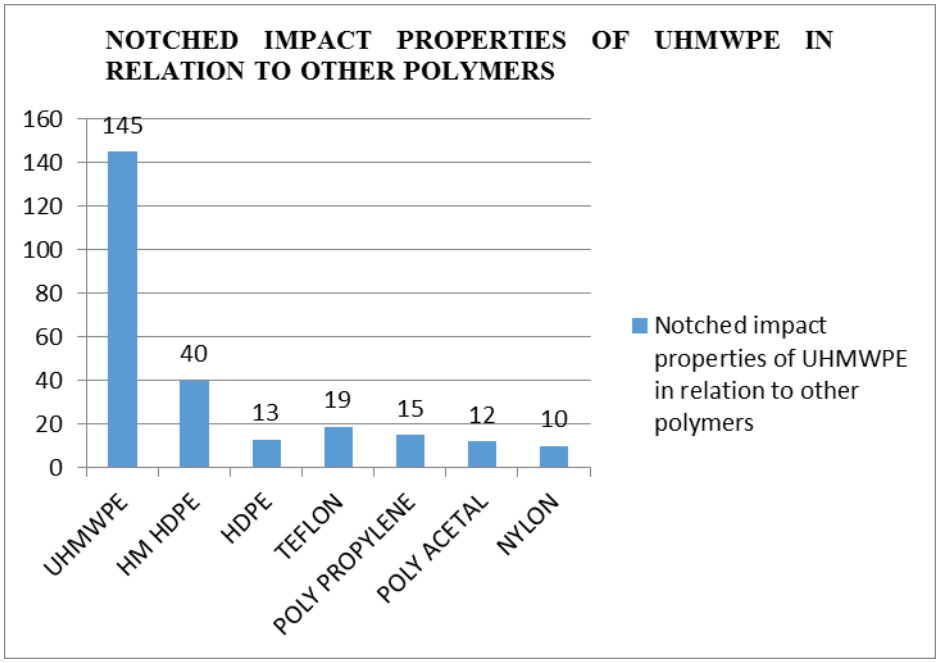

Fig 3. Graph of Comparison of Notched Impact Strength of UHMWPE

(Source: Hand Book of UHMWPE)

VI. FORMATION OF UHMWPE

Polyethylene consists of hydrogen and carbon and UHMWPE is polymerized from ethylene gas. The main ingredients of UHMWPE are ethylene, hydrogen and titanium tetra chloride. The polymerization takes place in a solvent used for mass and heat transfer. As the ethylene is a reactive gas, polymerization is carried out in a specialized production plant capable of handling potentially dangerous chemicals. Titanium tetra chloride acts as a catalyst which helps in producing white UHMWPE powder with reduced impurities. Thus produced UHMWPE powders are grouped in three types TYPE 1, TYPE 2 and TYPE 3 resins as per their molecular weight. The traces of impurities of titanium, aluminium and chlorine are residuals from the catalyst whereas the trace levels of calcium and ash depends upon the storage and handling of the powder after polymerization.

VII. PROCESSING OF UHMWPE

UHMWPE is produced by a chemical process as a powder which must be compacted into a solid before it can be used to manufacturing a component. In Earlier years compaction of the powder is achieved by physical compaction in which the polymeric powder melts and the particles then adhere to each other, and chemical compaction in which the polymeric chains become interpenetrated. Both of these processes depend on the local temperature for which pressure is applied. The major defect found were the voids in badly compacted materials possibly causing inferior mechanical properties in the resulting mass. And because of impurities in the equipment processing inclusions were also found. Upon research to overcome the defects and to improve the properties of UHMWPE, compaction is achieved by one of three processes: Ram Extrusion, Slab Compression Moulding or Direct Compression Moulding of a component. The

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disadvantage of ram extrusion and slab compression moulding is that they may not produce uniform conditions in the compacted mass. In the past these techniques have used calcium stearate as an additive to stabilize the residue of the catalyzer, in order to make the material flow more easily and to minimize corrosion of the tools. Calcium stearate, however, may accelerate oxidative degradation of polyethylene after gamma irradiation in air and may also cause poor consolidation of the powder. It is therefore not now used. In direct compression moulding, if the surface is overheated there may be more rapid wear. In the case of slab compression and ram extrusion a solid block is produced from which a component is machined. With direct compression moulding a component is formed which requires little or no further machining, but the technique is expensive and hence not suitable.

VIII. SELECTION OF UHMWPE

The three grades of UHMWPE are TYPE 1, TYPE 2 & TYPE 3. They are classified according molecular weight. Under TYPE 1 is the GUR 1020, TYPE 2 is GUR 1050 and TYPE 3 is 1900 resin which is recommended for the manufacturing of medical components. From the researches it is clear that the variations between the material property of GUR and 1900 resins can be explained by the differences in the average resin particle size, the size distribution and morphology of resin particles. GUR has particle size of approximately 140µm whereas the mean particle size of 1900 resin is approximately 300µm. Therefore the distribution of the particles in GUR is compact when compared to 1900 resin. Moreover studies have shown that powder morphology of GUR resin is characterized by fine network of sub-micron sized fibrils. GUR 1050 has superior mechanical properties when compared to GUR 1020. Thus for all these reasons said above GUR 1050 TYPE 2 grade is chosen for manufacturing of tibial insert

IX. CAUSES OF WEAR OF UHMWPE - JUSTIFICATION FOR RECOMMENDING MACHINING PROCESS FOR TIBIAL INSERT

Researches on study concluded that UHMWPE is subjected to wear in three ways, due to delamination, abrasion and adhesion. Adhesion and abrasion can be controlled but the wear due to delamination has to be taken care as it is caused by the way in which the material is manufactured and sterilized. Sterilization cannot be skipped as the tibial insert is a medical component. Sterilization is done by gamma irradiation in air. In both the process of ram extrusion and direct compression the raw material has to be melted which results in inferior mechanical properties and further when it undergoes sterilization degradation of the molecules occurs. Moreover the melting point of UHMWPE is around 130 to 136 °C (266 to 277 °F) and it is not advisable to use UHMWPE fibers at temperatures exceeding 80 to 100 °C (176 to 212 °F) for long period of time as it becomes brittle. Hence machining of the UHMWPE block is recommended for medical components.

VI. CONCLUSION

Replacing UHMWPE over other polyethylene HXLPE has given tremendous result in terms of life. The total knee transplant with UHMWPE tibial insert gives minimal wear and the debris of polyethylene reacts minimally with the surrounding tissues. Studies have revealed that patient's undergone knee transplant does not have complain for at least ten years. Moreover the wear of insert can be controlled by the processing techniques.

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REFERENCES

[1] S. M. Kurtz, "The Required Mechanical Properties of Hip and Knee Components", 2003.

[2] Jasper Harris, "A study of the mechanical properties of Ultra High Molecular Weight Polyethylene (UHMWPE)

[3] EM. Brach del Prever, "State of the art of UHMWPE in orthopedics : Sterilisation and packaging"

[4] Steven M. Kurtz, "UHMWPE Biomaterials Handbook_ Ultra High Molecular Weight Polyethylene in Total Knee Transplant."

[5] Gordon Blunn, "Ultra high molecular-weight polyethylene (UHMWPE) in total knee replacement: Fabrication, sterilisation and wear" , The Bone & Joint Journal · October 2002

[6] A. Seth Greenwald and Christine S. Heim, "Ultra high molecular-weight polyethylene in Knee Arthroplasty".