Advances in Additive Manufacturing of Materials: Current status and emerging opportunities

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Lecture43

welcome back to this NPTEL course on additive manufacturing. this is one of the case study that I will be discussing on 3D printing of ceramic dental implants. as the title of this particular lecture mentions dental implants, so first I will introduce you to the dental implants. And then I will show you some of our most recent research results as part of a large translational program involving manufacturing partner that is a startup company based in Hyderabad as well as these three clinicians based in three different hospitals. One at Ramaiah University Applied Science, one at KGMU, King George's Medical University and one at Dattameghe Institute of Higher Medical Sciences, Wardha near Nagpur in Maharashtra. I will be showing you some of the results so that you know that how this research has taken up from design to clinical outcome.

And then I will also show you that our work on the 3D printing of ceramic implants. having said that, this is the topic that will be covered, clinical treatment of tooth loss. Tooth loss, it can be single tooth loss, it can be multiple tooth loss and this tooth loss, the clinical term is edentulism. introduction to dental implants, so one of the treatment option is that use of dental implants, conventional and additive manufacturing of dental implants that I will show you, surface treatment, how the implant surfaces are being treated, performance limiting property assessment like insertion torque study, fatigue study, preclinical and clinical study.

as I said that I will show you very briefly some of the clinical outcome of the patients are being treated with the make in India implants or indigeneously manufactured implants in India on Indian patients. therefore, those images may disturb through some viewers.   our apology for that and this will contain open mouth intraoperative images and some clinical images or video with human blood. if this some tooth is missing here, right? essentially both the sides this will be compressing and when you try to bite certain food particles, you have to apply the force from the top, you have to apply the force from the both the sides in order to crush and grind during and during the mastication process, if there is no teeth loss, so the any human being can eat properly. then if you have an implant and if you have a tooth loss, then one of the treatment option is this placing   the   implant   and   then   putting   the   prosthesis.

advantages of dental implants, it essentially restores partial or complete edentulism or toothlessness. As I said before, maintenance of the alveolar ridge height and width, maintenance of masticatory efficiency and also facial aesthetics. now when these implants are being manufactured by conventional manufacturing technique or 3D printing technique, one should know what would be the sizes, right. it is as I mentioned before that you know that if you do cranioplasty surgery for cranial treatment, I think I have shown you some case study on that. Then you have noticed that this cranioplasty bone flap must be patient specific that means no single size fits all but the dental implants which is for public health care, this typically our jawbone anatomy essentially if you carefully consider jawbone anatomy particularly maxilla and mandible, mandible is a lower jawbone and maxilla   is   upper   jawbone.

There are specific sizes of these particular implants. for example anatomical location with respect to size, now if you look at this top part this one of the cross section has been shown here, so if you look at this particularly top part it is 3.7 mm and length is 8 to 12 mm. most cases, most of the implants that the patients need and then according to our experiences is around 4.2 mm, 4.

2 to 4.7 mm diameter and length is 6 to 8 mm. Then comes this lower mandible that is lower jawbone that is mandible, it is 4.7 to 5.5 and then also 3.

7 to 4.2 mm. And this length as you see it can vary between 8 to 12 or 10 to 14 mm and diameter it can vary from 3.7 to 5.5 mm this particular image has been essentially constructed using SERVIER that is the open source platform that we have used. what is a dental implant according to the FDA definition that is US Food and Drug Administration definition, this an endosseous dental implant is intended to be surgically placed in the bone of the upper and lower jaw arches and to provide support for prosthetic devices such as artificial teeth in order to restore a patient's chewing function.

 That is the FDA definition. And you can see this is that implants. It has been shown like it has been placed in the lower jaw. classification based on the implant placement in tissues, it can be classified as epiosteal implants, transosteal implants and endosteal implants, endosteal implants you can see that is a 2-piece or 3-piece implants that has been shown. biometrics for implant assembly either metallic implants or non-metallic ceramic implants like alumina zirconia or zirconia alumina and metallic implants stainless steel Ti6Al4V and so on.

 end-to-end technology development for dental implants, so design and manufacturing of implants. Then comes in silico biomechanical assessment for any new implant design. One has to do finite element analysis to show that if the implants is virtually implanted in the jaw bone, what would be the one major strain that will be generated and whether it will be in clinically acceptable bone remodeling range. Then, the surface treatment, so if the surface treatment is done, how that will influence the biocompatibility property of this material. therefore, in vitro cytocompatibility, in vitro means experiments which are conducted using glassware.

 Then comes performance qualification assessment like insertion and removal torque. there you can use the porcine bone or human cadaver bone just to show that when you essentially implant these materials, what are the kind of torque that you need to place that implant. Then in vivo biocompatibility and osseointegration and pilot clinical study, clinical evaluation in human subjects. Now I come back to this jawbone anatomy which I have shown you few slides back just to explain you that in the jawbone in the maxillary mandible that there is also bone density that will vary. bone density in this dental implantology often follows misclassification.

 first of all if you look at this. femoral bone structure, you have a cortical bone that is outer cover, you have a cancellous or trabecular bone that is a spongy structure. here bone density in this particular region bone density will be lower and this cortical bone density will be higher. And in the dental implantology people use D1 bone, D2, D3, D4. D2, D3, D4 basically D1 is much stronger D1 bone, D4 is much weaker bone that means bone density is fairly low.

 And if you look at this maxilla region, so D2, D3, D4 are very commonly or very much clinically observed bone density or clinically recorded bone density in human patients in the upper jawbone. Now in other parts you have either D2, D3 and in some of the edges of the lower jawbone you can have D1 and D2 bone. from

these two slides, this one and similar slides where I have discussed jawbone anatomy, you have much clearer idea, I am talking about, I am referring to this particular slide, here I have discussed about implant sizes, And here I am essentially discussing you about the bone density. you know that when you manufacture the implants what would be the various sizes that are required to be manufactured and then when you place those implants in the human patients what are the range of bone density that essentially you can encounter. this is not only implant sizes but also bone density which are to be taken into considerations during this implantation in human patients, here again this particular sketches and schematic was used, we have used the Sarvia.

dental implants, so we can have single piece implants like this. and we can have one-piece implants like this, like it can be ceramic implant or metallic implant. You can have two-piece implants, two and three-piece dental implants that has been mentioned here and there can be different implant types. For example, this is a perfect cylindrical type of implants There is a single straight screw dental implants and there is a conical dental implants. you can see that essentially The fecal part is very much conical shaped.

And what are the implant component? You have the top part is a prosthetic tooth. this is also called crown. But dental implantology often people use the word prosthesis. whenever they mention prosthesis, they essentially refer to crown. Then you have a locking screw and you have a heeling abutment.

This heeling abutment is to be placed inside after few weeks of the placing the implants. first step is the step 1 is the placing the implants. Second step is the placing the abutment and locking screw and third one is the prosthetic crown. you can see this is the complete placement of this essentially. dental implants with prostheses which are used for the treatment of dentillism.

And these are ceramic implants, this is a single piece implants which goes directly into the implant and on the top of it you have the prostheses called crown which can be placed. a 3-piece dental implant consists of abutment, screw and locking screw and a synthetic tooth or crown is placed on the abutment, types of root form of this one that I have shown you in the last slide that it can be either cylindrical or very blunt. It can have a straight screw dental implants and conical screw dental implants. So, one thing I must mention here that implant design if you bring novelty in the implant design. it must be supported by the preclinical evidences with respect to already clinically used implants with different design concepts.

any patented designs or whenever you want to patent any design that patentable design efficacy must be supported by the preclinical and clinical evidences. this is just a two-stage, this is a video of the two-stage surgery. You can see that if the tooth is lost, now this part we have identified. You can get the CBCT image and then you can essentially see what is the bone density and so on. Then you make a cavity right there, cavity to place the implants very very carefully.

You will see that. And then after few weeks, then you put this abutments, cover screw, everything. And then after few weeks, you can put the essentially crown at the same place. once you place the crown, then patient's original mastication property, I mean that is restored. there are two type of implants which are currently used metallic and ceramic dental implants. by far around the world titanium dental implants is most commonly used whereas ceramic implants has started penetrating the market and ceramic implants are also increasingly being used.

mostly in European countries and also western countries. titanium implants, one of the main thing is that this is

the first scientific evidence or clinical evidences for good osseointegration. It has good strength and durability properties. Easy machining, it can be done in the conventional machining.

It is versatile. It is available 1 piece, 2 piece, 3 piece, total rehabilitation. Corrosion and less aesthetic often are challenges or issues. Ceramic implants, it has a better aesthetics, better osseointegration. Soft tissue attachment is very good.

there is no metallosis. in titanium implant for longer term uses in some of the clinical cases people reported the evidences of metallurgy whereas it is ceramic implants metal free. Mechanical reliability, complex manufacturing, single piece dental implants that must be used usually and also cost. Those are I have put a star mark just to show this can be often be challenges. to take ceramic implants to a very significant extent to clinics. you can see this is a single piece ceramic dental implants and these are like metallic implants as you have seen before also this kind of sketches.

types of dental implant surgery, implantation procedure. first is the tooth extraction, damaged tooth, then implant is placed, then abutment is placed, then crown is placed, this third stage. And implant system as I said, it can be single piece, immediately loaded implant, two-stage surgery. tooth extraction, implant placement, cover screw placement. Then you essentially allow healing to take place depending on the patient's conditions is around 12 to 16 weeks, sometimes even it is shorter.

Then healing abutment is placed, the gingival former, then abutment is placed, then crown is placed. there is two type of loading conditions like crown loading I am talking about. Whenever you are talking about loading, we are essentially referred to crown or prosthesis, immediate loading or delayed loading. Immediate loading means immediately after the implantation, delayed means after few weeks as I have mentioned before. Now one of the main thing that when you place any implants that stress shielding can take place depending on the bone conditions, the host bone conditions as well as that implant properties.

Now, stress distribution is this is essentially shown to the cortical bone. when you place the implants, there may be displacement locally in this host tissue or host bone areas that has been shown here. you have the cancellous bone and you have a cortical bone. A few years later, if you see this implant when it is integrated, you can see very clear evidences of the CBCT, cone beam computed tomography, X radiography that how this implants behave. this is a perfect osseointegration in this particular case after few years.

bone remodeling is a process by which osteoblasts or bone forming cells, they sense the mechanical signals, they get mature to osteocytes. you have that osteoblast that is the primary bone cells or bone forming cells and these osteocytes that is the mature bone cells. bone remodeling is essentially caused by mechanotransduction process. Mechanotransduction like sensing the mechanical signals and that essentially activates some downstream signaling procedures, signaling processes so that this maturation from osteoblast to osteocytes that is accomplished. perception of the applied load to bone by sensory cells is osteocytes, then signals into biochemical signals, receiving the signals by bone forming osteoblast and resorbing osteoclast cells and response of the aforementioned cells and a consequent of bone adaptation processes.

bone remodeling essentially means that as I said this process involving mechanotransduction process and then goes from osteoblast to osteocytes. this is the resorption, this is the homeostasis, this is the overuse and this is the pathological overload. bone remodeling essentially is favored when the microstrain in the neighboring host

bone is within some range And as you see that if it is 50 to 200, the resorption is greater than bone formation. Homeostasis resorption is roughly equivalent to bone formation. Then overuse resorption is less than bone formation and woven bone formation is facilitated when it is more than 4000 to 5000 microstrain.

there is a manufacturing processes can take place using conventional 9 axis manufacturing CNC machine that is being used very much state of the art more advanced facilities. These are conventional manufacturing processes. There is also additive manufacturing processes are slowly being used, are being evaluated for making them robust. Okay. typically it takes around 2 minutes or less than 2 minutes to manufacture dental implant.

At least that is our experience. When I said less than 2 minutes, when you use this 9-axis state of the CNC machine. additive manufacturing techniques in dentistry, what are the different techniques that can be possibly utilized there? one is the selective laser sintering or stereolithography, SLA. and also fused deposition modeling FDM, photopolymer jetting or powder bed 3D printing. But I will be showing you later that how additive manufacturing technique has been used in our collaboration with some of the manufacturing partners. majority of the dental implants for patient care currently being manufactured using CNC.

Now once the implant is manufactured, this implant surfaces need to be treated, surface treated and the surface modification can be done by conventional technique is by sandblasting and that is by acid etching. this is a very commonly used technique, it is called sandblasting acid etching You can take the sand blasted dental implants and you can put it inside the acid solution. The laser radiation like you can focus the laser beam on the metal implant surfaces, you can treat them, so this is the laser irradiated metal surfaces. There is also process called anodization, TiO2 layer formation on the very superficially and then plasma spraying that is that in this particular layer. dental implants essentially is plasma sprayed and hydroxyapatite can be deposited.

this plasma hydroxyapatite coated dental implants and hydroxyapatite coating is done for better osseointegration of these implants. what you can see on the Right hand side here, so this is the rough and polished combination. This is that 3D textured implants which is also commercially used. Then you have a polished dental implants, you have a rough and sandblasted and hydroxyapatite coated. So hydroxyapatite coated implants as I said that is coming from plasma spraying of hydroxyapatite so that you can get this hydroxyapatite   coated   implants.

what is the other surface treatment modification strategy? although it has not been clinically used very extensively, researchers have tried organic coating on the implant surfaces. This organic coating essentially have growth factors and combination of growth factors and combination of ECM proteins and polysaccharides. ECM is extracellular matrix protein and polysaccharides and then it is you can say essentially coated on the dental implants. there is also inorganic coating like hydroxyapatite as I mentioned to you, calcium phosphate, magnesium or graphene or carbon nanotube or nano diamond. many of these things have been investigated to a very small extent research wise because Their safety and efficacy is a primary concern to any clinicians whenever you say that you are using graphene, carbon nanotube and nano diamond.

Although they look very attractive from the materials innovation perspective, but clinical practice is very different from what we do in the typical universities research laboratory. what is the other things people have done just to get this antibacterial efficacy of these implants, people have doped silver to hydroxyapatite and by doping silver to hydroxyapatite, the silver based hydroxyapatite or essentially silver doped bioglasses that can be coated. what I am trying to say is that the silver doped Hydroxyapatite or bioglass coated implants that can

be used for anti-infection purpose because this should have antibacterial properties and therefore it can be used for this anti-infective dental implants. These are like different nanotopographies which you can preferentially introduce on the dental implants and then you can see these kind of pillars These pillars have some top diameter here and then some length and it is like 5 micron and then there is also certain nanotopographic features like holes or these kind of alternative very regular patterns that has been used on the dental implants. all those things can be done using the manufacturing tools people use in the field of nanotechnology.

those kind of processing tools can be used to introduce this kind of nanotopography on the dental implants. I am not aware that this kind of nanotopographies in the clinically used implants are used to a great extent. Then there is a other different type of topographies that you can introduce to mimic the extracellular matrix of tissues by pillars, pits, groups and gratings that pillars, pits, groups, then tubes and fibers and wires and also by raffining.   by   roughing   like   sandblasting.

This is like wires and this is like electrospun fibers. That electrospun fibers are also used or also investigated to introduce the surface modification. And this you can see this manufactured dental implants in India in one of the GMP facility. They have this 9-axis CNC machine and these are like dental implants. This is like metallic dental implants. And then when they are supplied to the clinicians for the clinical study, they are put it into a medical grade glass vial, then this implant holder titanium and this assembly and glass vial packed in blister pack, it goes for gamma sterilization, this primary packing, secondary packing, gamma sterilization and then it goes   to   the   clinicians   when   they   place   these   implants   into   the   patients.

what are the mechanisms? In sandblasting acid etching, I have mentioned you before SLA technique has been most widely used. I would like to substantiate this particular technique little bit more. you have a sand grains, you can alternatively use alumina. or zirconia. mostly people use alumina particles because they are harder particles,   much   harder   than   zirconia.

what they do? They do these micro dimples by impact this is a sandblasting machine. it is a kind of impact or erosion. you can essentially use an erosion tester for the sandblasting machine. it will erode away very preferentially the metallic surfaces or material surfaces at the point of impacts. Now, this sandblasting once it is done, so essentially you can do it like erosion tester or you can use a nozzle which will direct these particles at the   implants   at   a   high   velocity.

These are blasting particles. And then you can put it in the acid solution. This acid can be various combination. You can use HNO₃ HCl combination for example, in a specific ratio. And then implant with the blasted surface has   been   immersed   for   specific   time.

etching time is also important. etching solution composition is also important and then it will give you these etched surfaces. I will continue with this surface modification strategy for the ceramic implants in the next lecture. Thank you.