Physics in Teeth

As we grow into adults, our teeth undergo changes that usually do not concern us unless there is pain or expense. Toothaches and trips to the dentist cause concern, but most of the time our teeth play passive roles in our lives.

There are many applications of physics in our teeth and jaws—such as forces involved with biting, chewing, and erosion of teeth. In addition, *prosthetic* (replacement) devices such as bridges and crowns have to be biocompatible as well as have sufficient strength to function properly.

Sometimes we inherit less than perfectly arranged teeth. We usually see an orthodontist who uses a variety of procedures applying force to reposition and straighten the teeth.

We consider first the physics of normal teeth, the forces involved in biting, and the force of the bite limited by the jaw (masseter) muscles.

Next, we give simple examples of straightening and moving permanent teeth (*orthodontics*) and an example where the jaw is reshaped. Finally, we discuss a few prosthetic crowns and bridges.

Forces in Normal Teeth:

Most of us wish we had teeth that were perfect. Figure (1) depicts the normal 32 permanent adult teeth and a cross section of a typical permanent molar tooth. It is obvious that different teeth have different functions. The *incisors* and *cuspids* (sometimes called eye teeth or canine teeth) have single cutting or biting edges. They have single roots; the roots for the cuspids located in the upper jaw are the longest.

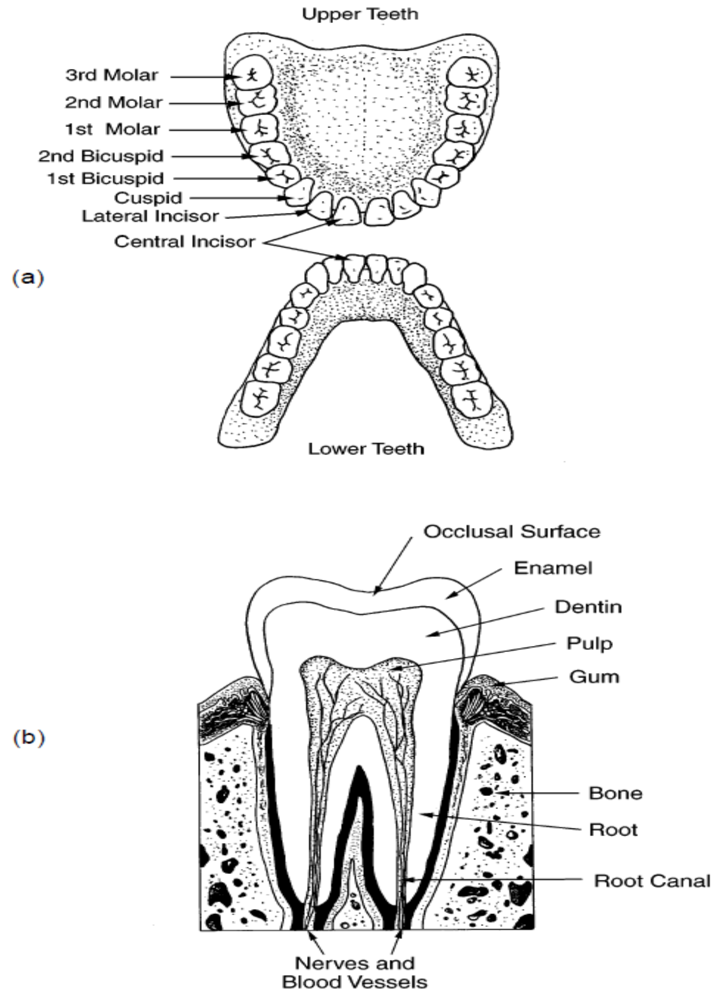

Figure (1): (a) The 32 normal permanent teeth of an adult (b) Cross –section view of an adult molar tooth

Behind the cuspids are the first and second *bicuspids*, followed by three molars, which usually have two or three roots. They are used for chewing or grinding food on the surface between the teeth (called the *occlusal surface*). Figure 2; shows a schematic view of the skull. The pivot for the jaw (*mandible*) is called the temporal-mandible joint (TMJ)— often a source of problems. The *masseter muscle* provides the main force for biting and chewing.

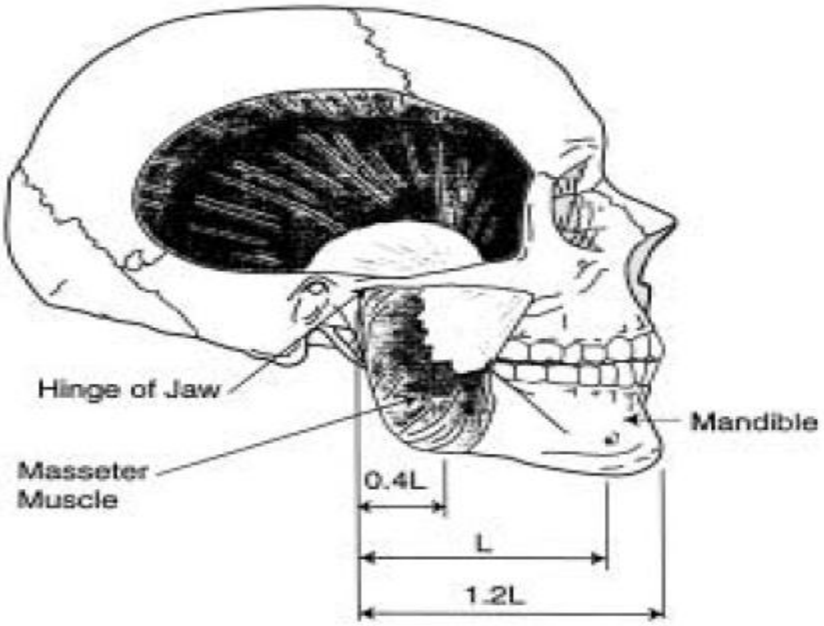

Figure (2): Schematic view of an adult skull showing some of the teeth and the masseter muscle that provides the closing and chewing action of the lower jaw (mandible) .The dimensions are in unites of L which is the distance of the first bicuspid from the hinge of the jaw 0.4 L is the approximate location of the distance of the masseter muscle from the hinge and 1.2 L is the distance of the central incisor from the hinge. The value of L is typically about 6.5 cm for women and 8 cm for men.

Scientists have measured the stress-strain behavior of the enamel and dentin components of teeth . A stress-strain curve for dentin is shown in Fig. 3.

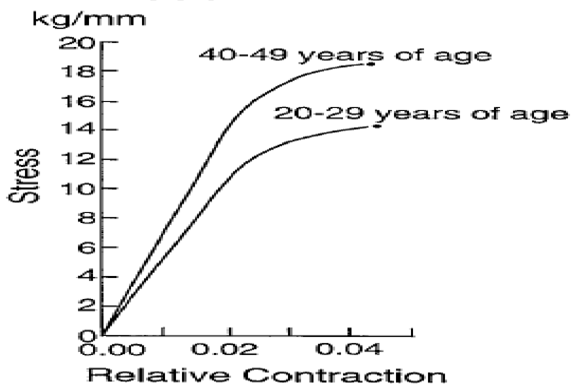

Figure 3: The stress-stain curve for wet dentin under compression for the premolar (bicuspids) teeth for adult in two different age groups. Young's modulus initially increases with age ,but later it drops slightly .The enamel surface has a Young's modulus about five times greater than that for dentin .Note the stress scale is a factor of 10 larger if given in N/mm^2.

The maximum force than one can exert, measured at the first molar occlusal surface (1st biscuspid), is about 650 N. If the area of contact is about 10 mm^2, the force per unit area is then nearly 65 N/mm^2 ($6.5 \times 107 N/m^2$ or kg/mm^2). The Hooke's law portion of the stress-strain curve in Fig. 3in kg/mm^2 for dentin shows about a 0.01 (1%) fractional compression of the tooth. Considering that enamel is stronger than dentin by a factor of five, the biting force is well below that where failure of the tooth would occur.

If we accidentally bite into a hard cherry stone or kernel of popcorn, the area of contact may be as small as 1 mm^2; then the compressive stress is about 650 N/mm^2 (65 kg/mm^2). Under these conditions, the tooth would fail. Many of us have learned this fact experimentally. A tooth that has been weakened by fillings or decay might be broken when you bite a hard, small object.

The 650 N biting force is supplied by the masseter muscles. we see that biting is a third class lever with the muscle close to the fulcrum of the jaw as shown in Fig. 2.

Because the molars are used for grinding food, they have large surface areas compared to the incisors, which act more like knives in the biting process. If the force from the masseter muscles were acting only on the central incisors and not on the molars, the net force would be less than 650 N by the ratio of L/1.2L or 540 N. This force is about equal to the weight of a small adult. You can imagine how effective the incisors would be when you visualize using a dull knife on an apple with a force about the same as the weight of a human.

Consider biting into an apple (see Fig. 4.). The teeth behave like the knife shown in (a). When the incisors first make contact with the apple, the stress (force/area) is very large because of the large applied force (assume 200 N) and the small area of the edge of the incisor teeth (perhaps 1 mm^2). This applied force leads to a stress of 200 N/mm^2 ($20 \times 10^7 N/m^2$), which is sufficiently large to rupture the apple (b) (and most other foods as well!). Once the apple's skin has been ruptured, then the front and back surfaces of the teeth make contact with the interior of the apple. The angle of the front incisors is about 60° as shown in (c) and (d) where the force of 200 N is still applied by the jaw on the front teeth. In the simplest approximation (d), the downward force is balanced by the two components of force F normal to the front and back surfaces of the incisors. These two forces can be large and push apart the two sides of the apple being bitten, causing the crack to spread.

Have you noticed that the permanent teeth of young adults appear very prominent in their jaws? This is particularly true of the front incisors. After 20 or 30 years this no longer seems to be the case. What has taken place is that the teeth wear; in some cases their length erodes as much as 0.1 mm/yr.

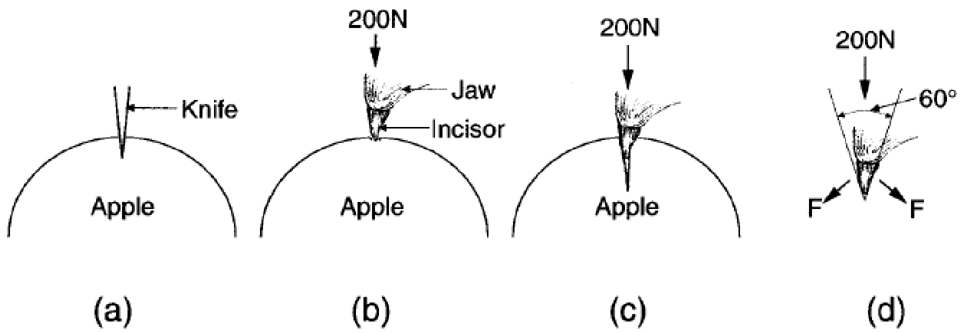

Figure 4: Schematic of the action of the biting behavior of an incisor tooth on an apple a) A knife cutting into an apple b) The incisor making contact with the apple and having sufficient force to cause the skin to rupture c) The incisor has penetrated the apple causing a crack to propagate d) The schematic behavior of the forces on the incisors .

Some Simple Cases of the Physics in Orthodontics

Everyone has seen a child with its thumb in its mouth. It is part of growing up and nearly all children do this and eventually the thumb sucking ends. Excessive thumb sucking can change the shape of the mouth as it can move front teeth. Most often, the two central incisors are pushed out and spread apart, which can lead to a large overbite as shown in Fig. 5a.

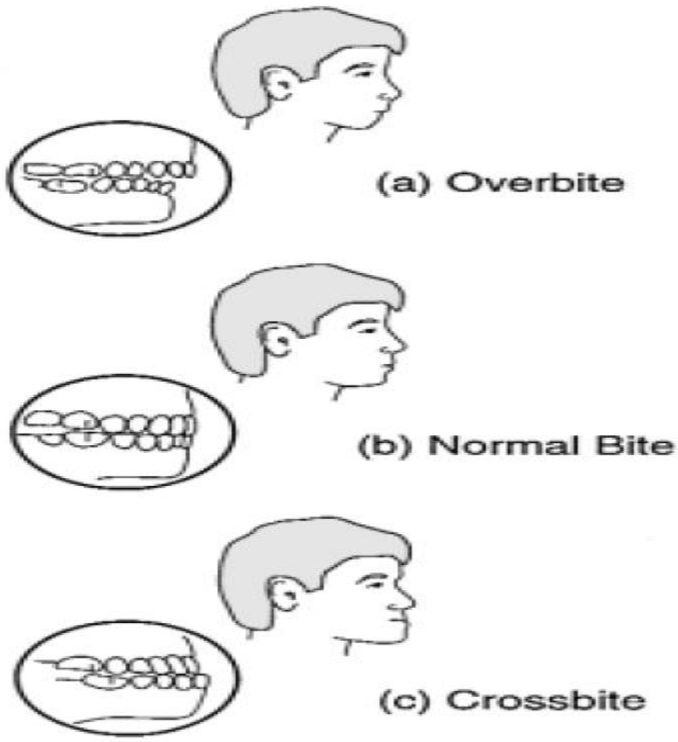

Figure 5: The location of the teeth in the upper jaw with respect to frontal teeth n the lower jaw leads to several conditions a) overbite b) normal bite c) cross bite

How can those teeth be brought back to the desired location? One way is shown in Fig. 6a where a mechanical connection is made to the teeth that need to be moved and force is supplied by the external headgear.
Depending upon the initial conditions of the teeth, other methods such as adding a rubber band to provide tension between the teeth (shown in Fig. 6b) may be all that is needed to move the teeth together. Sometimes a tooth needs to be moved a small amount; this can often be accomplished by appropriate spring wires as shown in Fig. 6c. It is surprising how small the force needs to be, in this case only about 1 N.

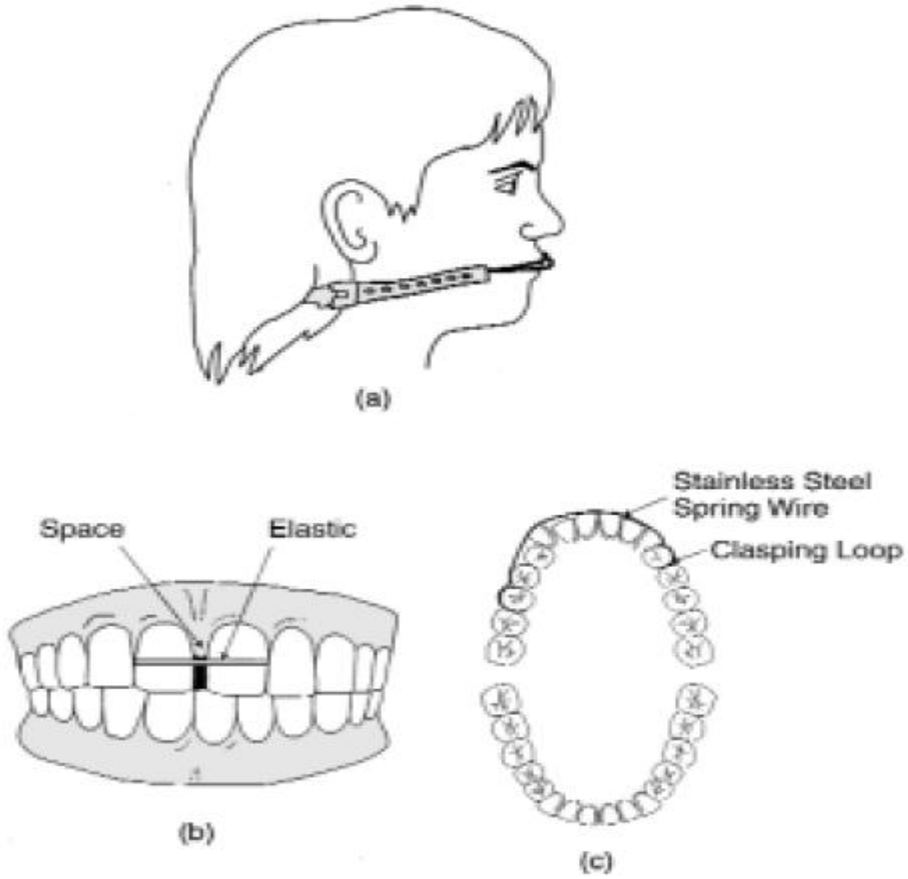

Figure 6: a) sometimes in orthodontic work the teeth are moved by external headgear which supplies the force on the teeth b) for some teeth with too large a gap between them ,the force of a rubber band is sufficient c) a simple brace (stainless spring steel) arrangement used to provide a small force (1-2 N) on a cuspid that needs to be moved into better alignment with the upper jaw.

However, we should remember that in the early years, the erupting teeth are guided by their surroundings: the jaw and the neighboring teeth.

There are many orthodontic appliances and, to a large degree, they depend on the skill of the orthodontist. Figure 7 shows different methods to apply forces to move teeth. Figure 7a represents a fixed orthodontic apparatus. It has several features common to straightening and moving teeth, e.g., the banding and brackets are often used along with the arch wire to form the main support for other attachments to move teeth. Clever arrangements of the attachment bands, arch wire, and elastic bands can accomplish complicated movements of the teeth.

Figure 7b depicts an adjustable, removable appliance designed to widen the jaws and straighten the front teeth. The adjustment moves about 0.8 mm per turn where each day one quarter of a turn is made.

The total movement may be as much as one cm.

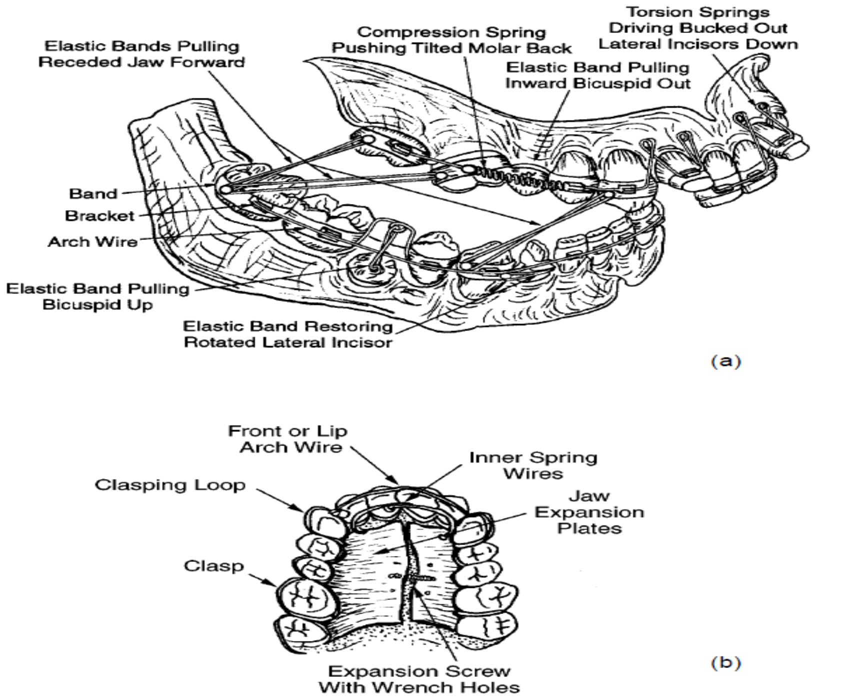

Figure 7: Two schematic orthodontic arrangements a) an exaggerated case of a fixed orthodontic apparatus used to move and control teeth in the upper and lower right jaw (left side not shown) b) an adjustable movable appliance used to widen the upper jaw while at the same time straightening the front teeth .This arrangement ,when modified can also be used to reduce the size of the jaw.

Figure 8 shows two examples of moving teeth: (a) A spring under compression is used to widen the space for the middle tooth. (b) A spring under tension moves a tooth to close a gap. These springs supply a variable force for compression or expansion. Typically, the force will be about 1 N, which reduces as the tooth moves. Note that the springs are connected to the brackets attached to the teeth. The bracket on the tooth to be moved can slide guided by the arch wire; the other bracket is fixed to the arch wire.

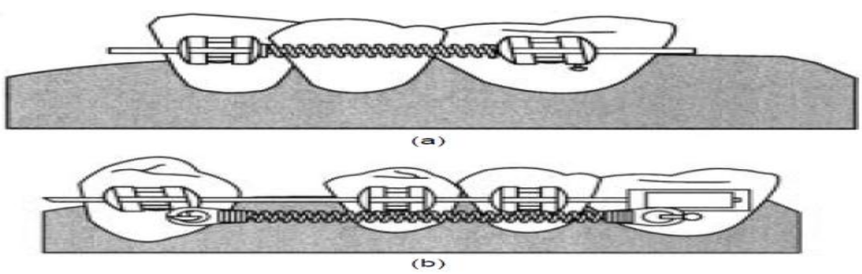

Figure 8: a) a compressed spring arrangement is used to move an improperly aligned tooth to a different position b) a spring under tension supplies a force to move a tooth to fill a gap

Crowns, Bridges, and Implants:

Despite our efforts to preserve our teeth, an accident can lead to broken teeth, or one or more teeth have decayed. We may be unfortunate and inherit genes that do not favor long-lasting teeth. Many people need dental repair for damaged or missing teeth. The simplest repair is a simple filling. In many cases the filling does not significantly reduce the strength of the tooth; the repair may last a lifetime if properly done and given proper care.

Let us consider a more drastic case where the tooth has had extensive fillings and now is not structurally sound. How can one preserve the tooth and the function it provides? One approach is to *crown* the tooth, as shown in Fig. 9. This is a *prosthesis* and involves grinding away the damaged area of the tooth and replacing it with an artificial tooth. The shape of the crown is determined from molds made of the patient’s mouth, ensuring a custom fit. The crown is often made of a strong gold alloy with a porcelain face, in a color matching the permanent teeth and cemented in place. The use of gold is not a new idea-the Etruscans, over 3000 years ago, made simple crowns. We now know that gold is inert chemically; it has a strength greater than the original teeth and can easily be cast in a mold. These repairs are attractive, functional, easy to keep clean, and long lasting.

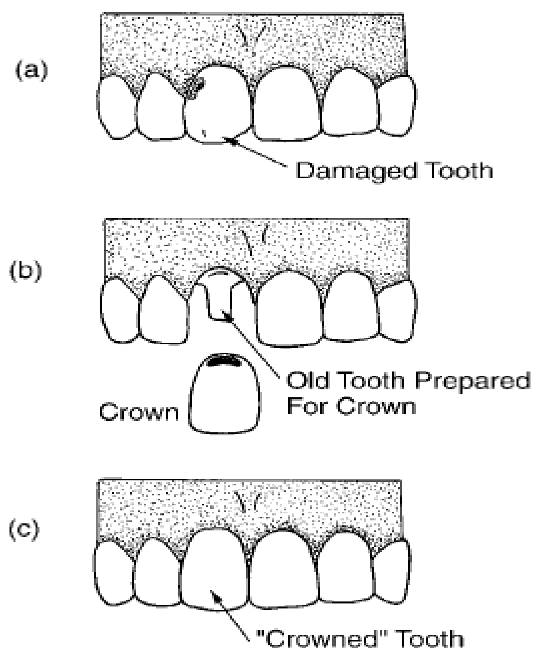

Figure 9: a) a tooth damaged by decay b) The damaged tooth is prepared for a crown .An impression of the natural teeth is used to prepare the crown replacement c) shows the crown cemented in place.

Suppose that the tooth has been damaged so much that it needs to be removed. You might be faced with the prospect of a "bridge" prosthesis. For this to work, there have to be teeth on both sides of the missing tooth for attaching the bridge. Figure 10 shows an example of a bridge which uses the adjacent teeth.

A bridge may fail when the material properties of the gold alloy are improperly used, such as an improper design with insufficient strength between the replacement tooth and its attachment to the neighboring teeth. If the cross-sectional area on both sides of the replacement tooth is insufficient, then the use of the bridge in chewing could cause the replacement tooth to flex eventually breaking the connections. Engineers call this a shearing force, which is another way of classifying the strength of materials.

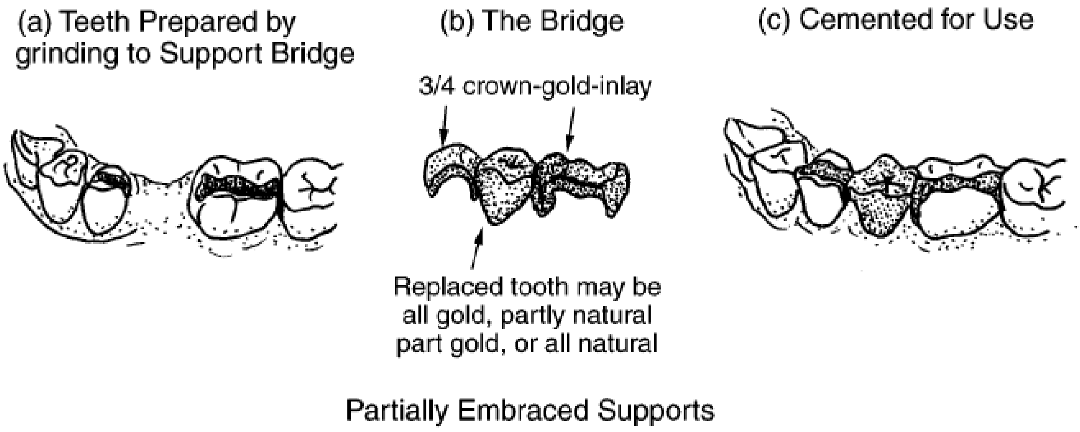

Figure 10: A simple bridge prosthesis a) the missing tooth and the teeth on either side prepared by grinding to support the bridge b) the bridge replacement and the supporting structures for either side of the missing tooth .A mold of the region of the missing tooth and of the teeth in the upper and lower jaw is needed to ensure the correct fit as shown n c) for the bridge cemented into place .

What happens if a nearby tooth cannot be used for a support? Fig. 11 shows an implanted peg screwed directly into the jaw. The prosthetic tooth is then cemented to the peg. This type of prosthesis is more difficult to keep clean, but acceptable in many situations.

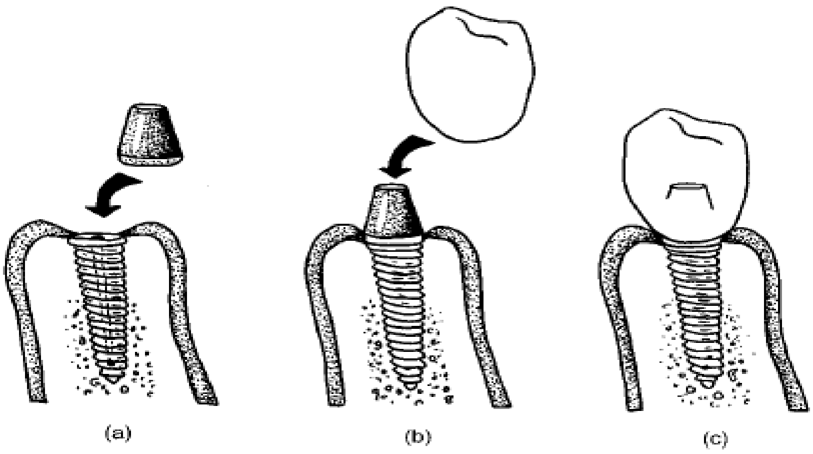

Figure 11: In a situation where there are no adjacent teeth to use for a bridge , sometimes an implant is used instead a) The implant is screwed into the jaw and the tissue and jaw are allowed to heal b) Later , the peg to hold the tooth is installed c) the finished tooth cemented in place.

Of course, the materials for tooth repair need to be biocompatible. That is not a problem. Metals are often used to strengthen a body part (e.g., the hip transplant). The forces on prosthetic teeth go directly to the jaw like natural teeth. An implanted tooth is a very successful prosthesis.