Chapter 6: Movement

In the living body, elements relate each other, so that the whole body realizes the movement as represented by the muscular-skeletal system. In this chapter, we learn basic engineering related to the interface: interaction between elements, lubrication, and wear.

6.1 Balance among forces and control of movement

6.1.1 Balance among forces

"Force" is defined as a vector which changes the velocity or the form of an object. When the force is not applied, the object keeps the shape and the velocity as the uniform linear motion.

The **hip joint** consists of a combination of a sphere (the femoral head) and a cup (the acetabular) (**Fig. 6.1**). In the standing position, the hip joint supports the body weight. When you stand on both legs, each hip joint supports each half of the body weight. When you stand on one leg, one hip joint supports the entire body weight.

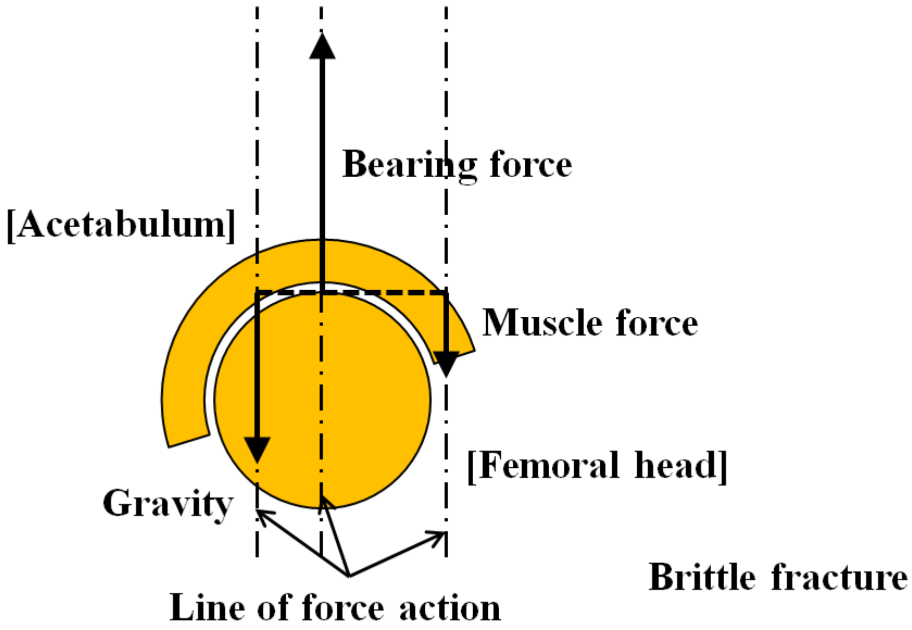

Fig. 6.1: Force at hip joint.

At the hip joint surface, a force that exceeds the weight is applied. It supports acceleration at the exercise. It plays a role of damper for an impact force applied in a short time.

The muscle generates the force to control the movement at the joint. The line of action of the gravitational force by weight does not always coincide with the line of action of the supporting force at the hip joint. When there is a deviation between the lines of action, the **momentum force** occurs around the joint. The balances both at the force and at the moment demand the force exceeding the weight at the articular surface as the fulcrum (Q 6.1) (Fig. 6.1).

The force acting apart from the fulcrum generates a large moment, which is called the **principle of leverage**. The leverage reduces the force in inverse proportion to the distance from the fulcrum. The leverage increases the working distance (or speed) in proportion to the distance from the fulcrum (**Fig. 6.2**).

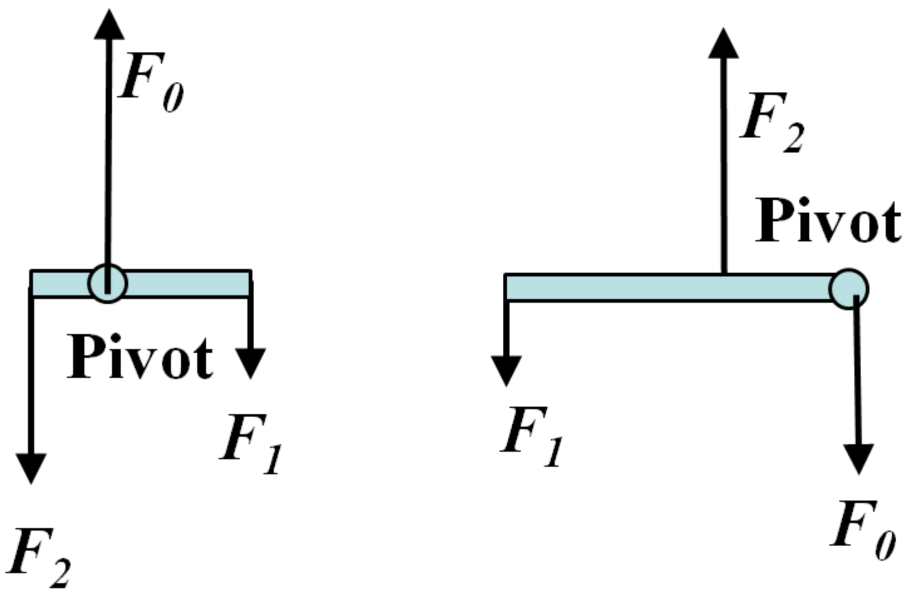

Fig. 6.2: Principle of leverage.

Even if the speed is constant, the direction of movement changes in a circular motion. In this case, a force is acting to the direction to the center of the arc. The force is called the **centripetal force** F in Eq. 6.1 (**Fig. 6.3** (a)).

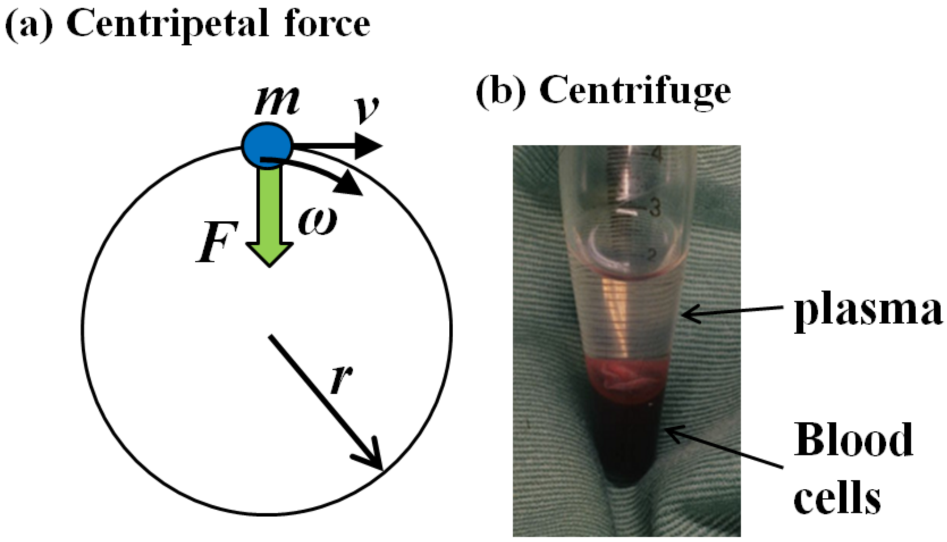

Fig.6.3: Circular motion and Centrifugation.

$$F = m v^2 / r = m r \omega^2 \quad (6.1)$$

In equation (6.1), m is the mass [kg], v is the speed [m s^{-1}], r is the radius [m], and ω is the angular velocity [rad s^{-1}].

In a **centrifuge**, a centrifugal force is caused by the rotational movement. The centrifuge is applied to separation of solutes in the physiological liquid, to separation of blood cells and plasma in the blood (Fig. 6.3 (b)), and to separation of cells suspended in the medium. By interposing a non-aqueous solution of the appropriate density, the erythrocytes can be distinguished in accordance with the density of the containing polymer.

The deformability of red blood cells of the high density is low [26]. The red blood cell deforms from biconcave to ellipsoid in a shear flow field. The deformation can be quantitatively described by the deformation ratio y (Eq. 6.2).

$$y = (a - b) / (a + b) \tag{6.2}$$

In Eq. 6.2, a is the length of the major axis of the ellipsoid, b is the length of the minor axis of the ellipsoid (**Fig. 6.4**). The value of y is zero at a sphere ($a = b$), and approaches to unity as the deformation of the ellipsoid advances ($a >> b$). The deformation ratio of the red blood cell in the shear field can be measured in the **counter rotating rheoscope** (see 4.2.4) (**Fig. 6.5**).

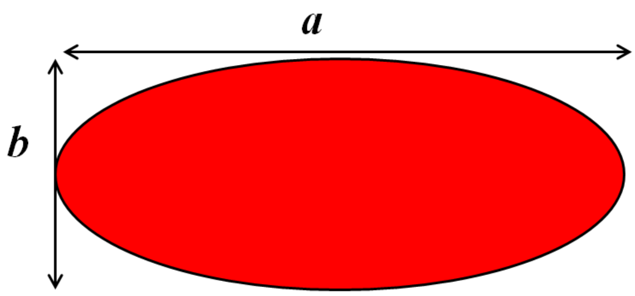

Fig. 6.4: Deformation ratio.

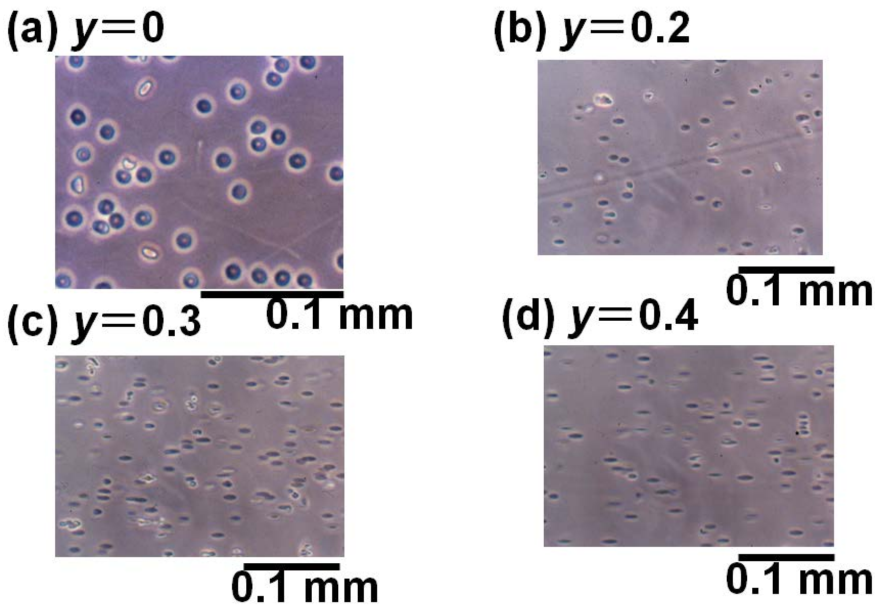

Fig. 6.5: Erythrocyte deformation in shear field.

If the maximum deformation ratio y_0 and the characteristic stress τ_0 are introduced for the evaluation index of deformability, the deformation properties of the ellipsoid of red blood cells in shear flow can be approximated as shown in **Fig. 6.6** (see Eq. 6.4).

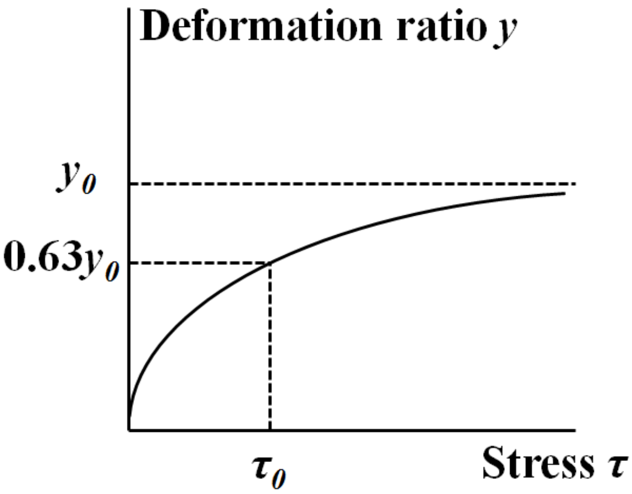

Fig. 6.6: Deformability of erythrocyte.

$$y = y_0\left(1 - e^{-\frac{\tau}{\tau_0}}\right) \tag{6.3}$$

In Eq. 6.3, τ is the stress, and τ_0 is the stress when y reaches to the 63% of y_0. A red blood cell of high density has the small y_0 (maximum deformation ratio) and the big τ_0 (characteristic stress). The red blood cell of high density cannot deform greatly. The red blood cell of high density is not sensitive to the stress. The deformability of red blood cells may decrease during the circulation after the production at the bone marrow.

The centrifuge can be applied to realize the **excessive gravity** environment. When the muscle cells are cultured in excessive gravity, some of the cells are destroyed, are thinned out, and are subsequently promoted to form myotubes (**Fig. 6.7**) [40].

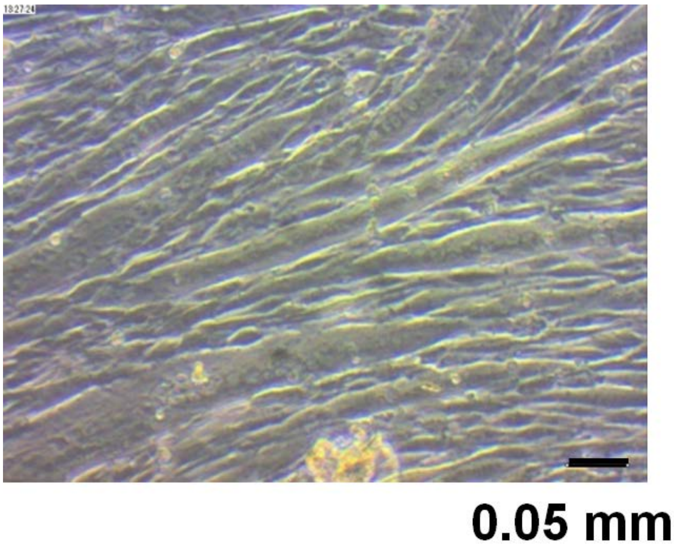

Fig. 6.7: Myoblasts differentiate to myotubes.

6.1.2 Description of movement

The movement of an object in the three-dimensional space is expressed by translational and rotational movements. The number of independent variables is called the **degree of freedom**. In the three-dimensional space, both three directions of translational movement (x, y, z) and three rotational motions around the three axes (x, y, z) are permissible, which makes six degrees of freedom (**Fig. 6.8**).

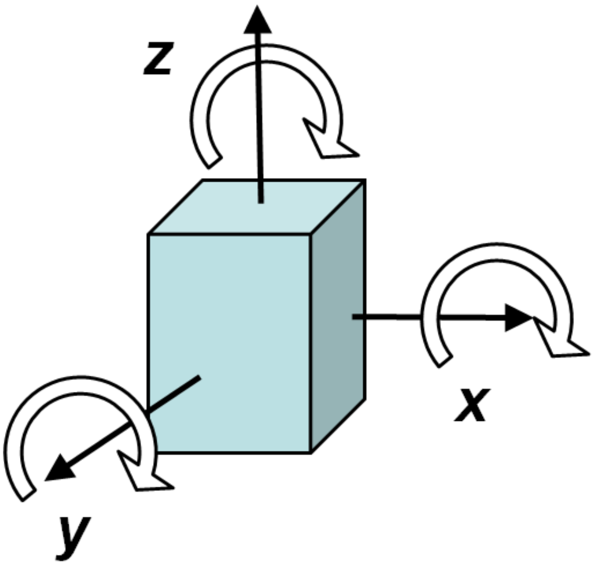

Fig. 6.8: Degree of freedom (Translation, Rotation).

In the movement in the *x*-*y* plane, the degrees of freedom is equal to three: two translational movements (*x*, *y*), and one rotational movement around the *z*-axis. When the movement of the object is constrained, the degree of freedom is reduced. The degree of freedom on the movement in a system, which consists of multiple objects, is represented by a set of the degree of the movement of each object.

Because the human joint has complicated movement, a special method is required to describe the movement. In the standing position of the human, three planes are defined: the frontal plane (vertical plane between the front and rear), the sagittal plane (vertical plane between the left and the right), and the horizontal plane. Several movements are defined around the trunk: flexion-extension, internal-external rotation, adduction-abduction, and varus-valgus (**Fig. 6.9**). Since the articular surface is not a simple spherical surface, the center of rotation according to each curvature of the surface is not fixed to one point [3].

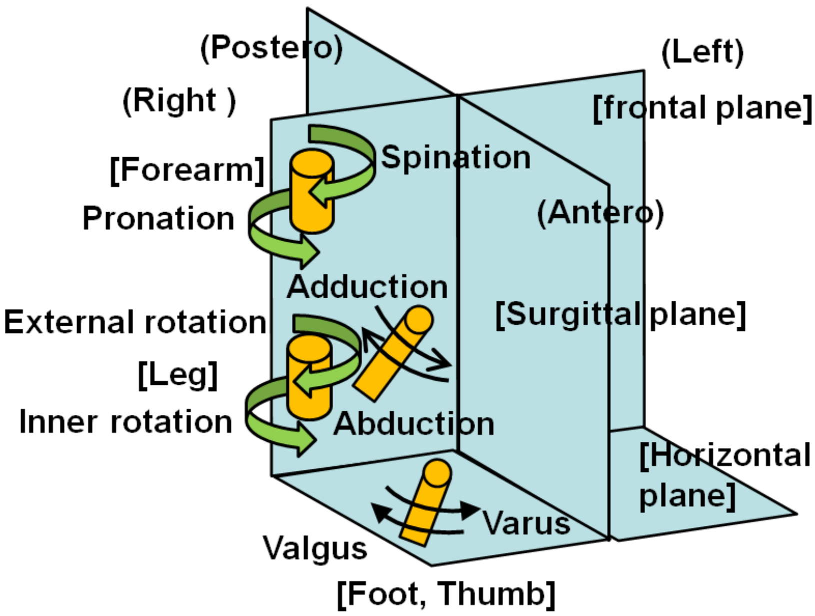

Fig. 6.9: Motion direction.

The standards of the position and direction are required to represent the movement in space. Coordinates are used as the reference for the position. For the movement of a human body, the special definition is necessary for the coordinates.

In the durability test of the ceramic hip joint, the slightly shifted center of rotation causes the partial contact of the friction surfaces, which leads to **brittle fracture**. On the other hand, when it is implanted in a living body, the joint actuates along the friction surface. Adjustment of the center of rotation is important in the test *in vitro* (see 3.1.2): a fixing method with “exploring the operating position in the movement”.

When the restoring force acts against the displacement, the repetitive movement back to the original position makes vibration. The **natural frequency** of a vibrating system depends on the mass and the restoring force. The natural frequency is low with large mass, and high with large restoring force. The change of the natural frequency of the object can be applied to detect the adsorbed material on the object [41].

6.2 Lubrication and wear

6.2.1 Machine elements and systems

The machine consists of multiple **elements**. Between the elements, the force is transferred through fixation or relative motion. The elements are classified into several groups: the fastening elements, the transmission elements, the liquid transfer elements, the sealing elements, the guiding elements, the motion conversion elements, and the dumping elements.

Screws, bolts, nuts, washers, rivets, keys, and pins are included in the fastening elements. The transmission elements include gears, chains, belts, and pulleys. The liquid transfer elements include pipe fittings and valves. Seals and O rings are included in the sealing elements. The guiding elements include shafts and bearings. The motion conversion elements include cams, link mechanisms, and power springs. The dumping elements include springs and dampers.

A cam is a disk-shaped element attached to a rotating shaft. By variations of “the distance between the rotation axis and the curved surface” in accordance with the rotation angle, the cam converts the rotary motion to the linear reciprocating motion.

In the **piston-bellows type** of artificial heart, the amplitude of the reciprocating motion of the piston is changed by the eccentric distance of the **cylindrical cam** (**Fig. 6.10**). While the reciprocating distance of the piston remains constant, the waveform of the piston motion can be changed: the shape of the cam, or the removal of the part of the reciprocating motion of the piston (**Fig. 6.11**).

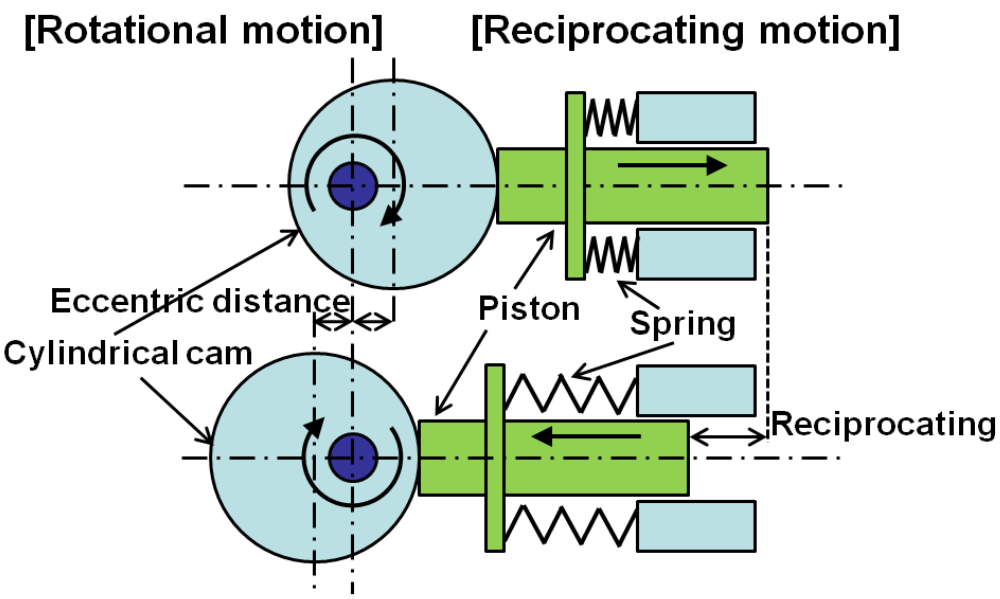

Fig. 6.10: Cylindrical cam.

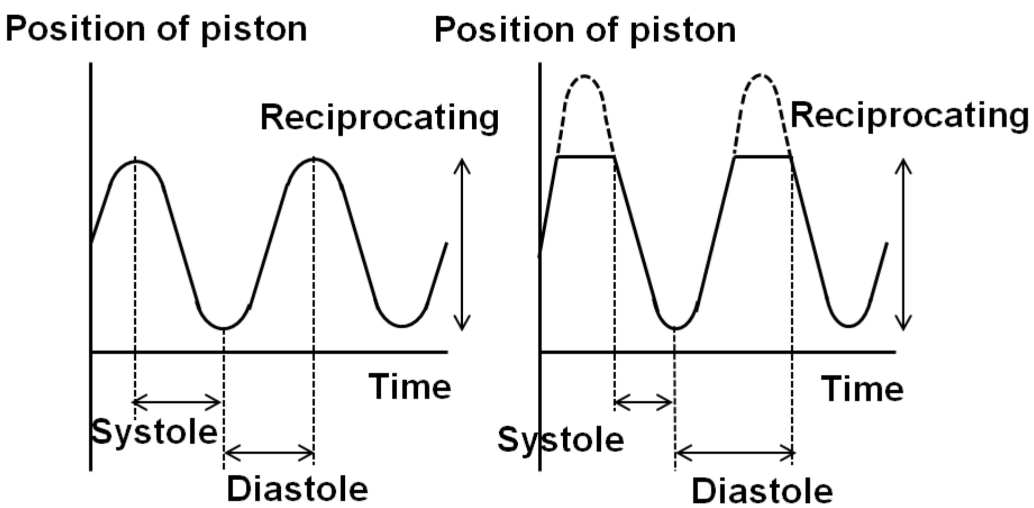

Fig. 6.11: Motion of piston.

In accordance with the reciprocating motion of the piston, ventricular volume changes periodically. The pulsatile flow waveform can be controlled by the motion of the piston [42]. Is the pulsatile flow required for blood circulation? What kind of waveform of pulsatile flow should the artificial heart supply to the blood circulation?

The damper attenuates vibration (**Fig. 6.12**). The damping of the fastest approach to saturation without vibration is called the **critical damping**. When the tracing of the displacement y is represented by the equation (6.4), t_0 is called the **time constant**.

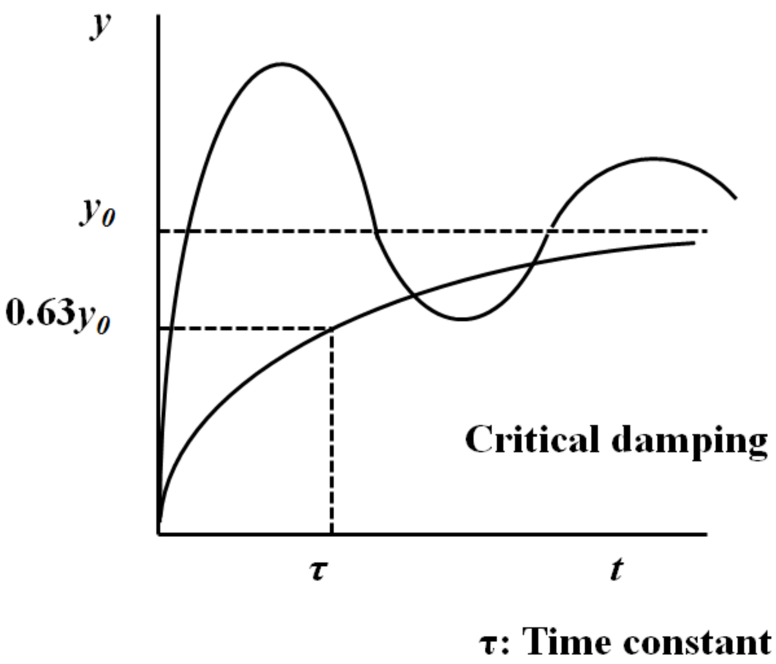

Fig. 6.12: Damping of vibration.

$$y = y_0\left(1 - e^{-\frac{t}{t_0}}\right) \tag{6.4}$$

In Eq. 6.4, y_0 is the saturation value of the displacement, t is the time, and e is the base of natural logarithms ($e \fallingdotseq 2.72$). The time constant t_0 corresponds to the time, when y reaches to 63% of the saturation value (see Eq. (6.3)).

A machine can be considered as a **system**: the machine consists of several elements, the machine has relationships between the elements, and the machine realizes operation as a whole. In order to achieve the desired movement, the motion status should be detected and the following movement should be adjusted. The adjustment is called

control. In the control, the subject is considered as a system. The interaction between the elements, the target value, and the situation of the operation are treated with signal flows (**Fig. 6.13**).

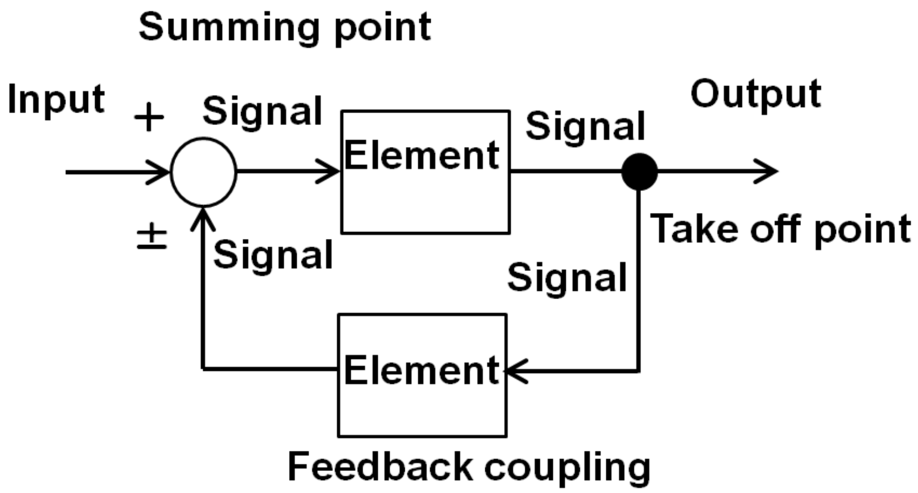

Fig. 6.13: Control.

Cells assemble to make a tissue. Tissues assemble to make an organ. Organs assemble to make system. Systems assemble to make an individual. The larger level is considered as a system, which consists of elements of the smaller level. The maintenance of homeostasis with adaptation to the surrounding environment can be considered as a control in the system.

For example, a cell can be considered as a system. The cell consists of the nucleus, the cytoplasm, and the cell membrane. Between the elements, signals and substances are transferred. The cell has several behaviors: deformation, migration, proliferation, differentiation, absorption, and excretion. The cell responds to the stimulations: deformation and movement of the surrounding tissue, the flow of the surrounding fluid, contact with the surrounding cells and tissues, exchange of substances and signals with the surrounding environment, and change of the internal state (**Fig. 6.14**).

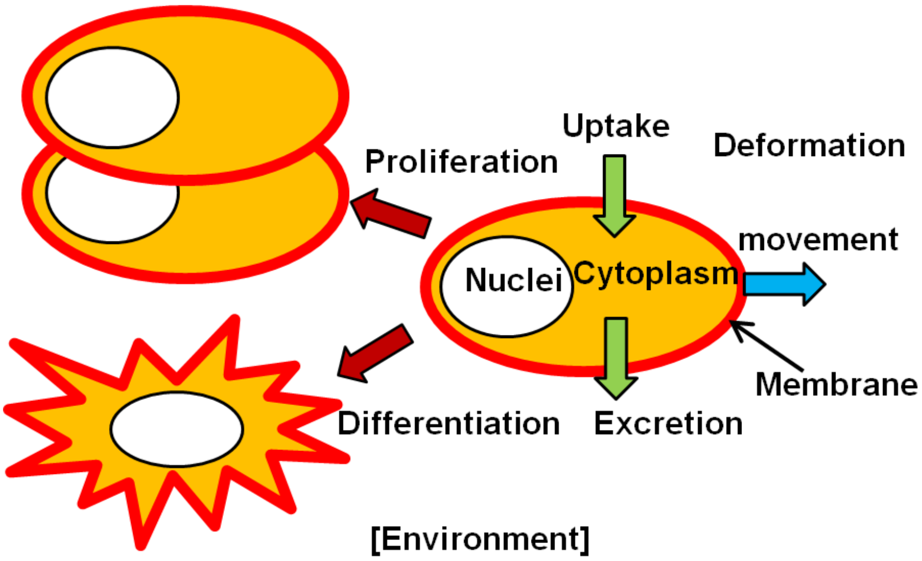

Fig. 6.14: Biological cell.

The **individual death** should be considered at the system level (**Fig. 6.15**). The death is conventionally determined with the cardiac arrest, the respiratory arrest, and the brain function arrest.

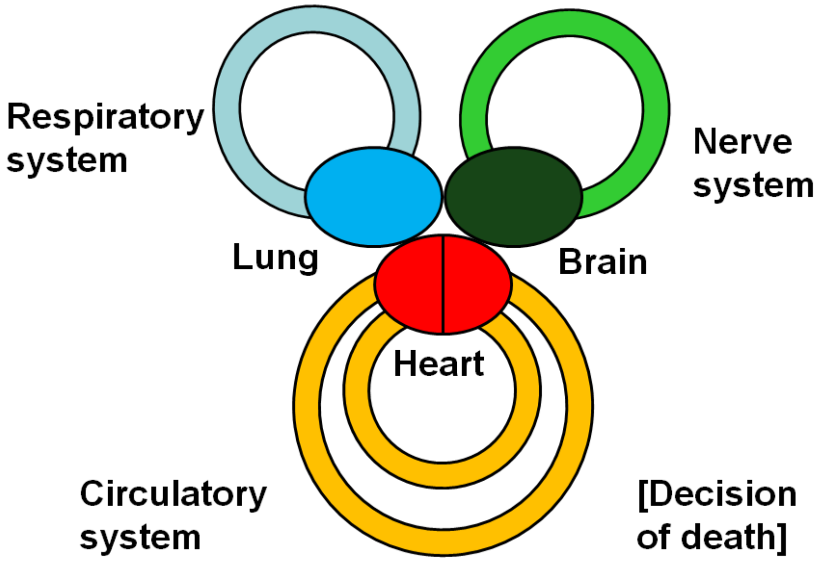

Fig. 6.15: System in organ.

The “cardiac arrest” cannot be determined on the beating of the heart alone. The cardiac arrest should mean the functional arrest of "blood circulatory system". A beating heart alone is not enough to maintain the life. The blood circulation cannot be maintained, when a blood vessel is blocked. When the bleeding cannot be controlled, it cannot be maintained, either. You can understand that the artificial heart alone cannot make the permanent life.

The respiratory arrest and the brain function arrest are similar to the cardiac arrest. The individual death should be judged on the system level rather than the organ level: the respiratory system and the nervous system, rather than the lung and the brain.

6.2.2 Coefficient of friction

The relative movement between the objects, while keep contact each other, is classified into two groups: the slip (including the rotation), and the rolling. During the relative motion between the objects, the force acting in the tangential direction at the interface is called the **frictional force**. Between the objects, the stationary and the relative movements depend on the frictional force acting at the contact surface. The skin grabs the object by the frictional force.

The supporting force, which acts perpendicular to the contacting surface, is called the **normal force**. The ratio μ between the frictional force Fs and the normal force Fn, which is calculated by Eq. 6.5, is called the **coefficient of friction**.

$$\mu = Fs / Fn \qquad (6.5)$$

The friction is called the **static friction**, when the object is stationary. The friction, on the other hand, is called the **kinetic friction** during the motion. When the inclination angle θ of the slope increases, the object starts sliding slopes at the value θ_0. The θ is called **friction angle** (**Fig. 6.16**). The tan $\theta_0 = \mu_0$ is called the maximum **coefficient of static friction**.

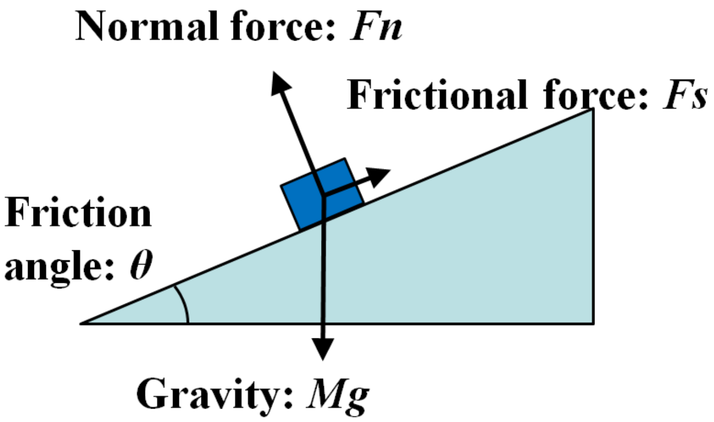

Fig. 6.16: Friction angle.

$$(M\,g\,\sin\theta_0)/(M\,g\,\cos\theta_0) = \tan\theta_0 = \mu_0 \qquad (6.6)$$

In equation (6.6), M is the mass of the object, g is the gravitational acceleration.

6.2.3 Contact

On the solid surface, there are large and small irregularities (see 7.1.3 surface roughness). The area, where the solids contact directly each other, is called the "**real contact area**". The real contact area is very small compared with the "**apparent contact area**", even when the apparent flat planes contact each other (**Fig. 6.17**).

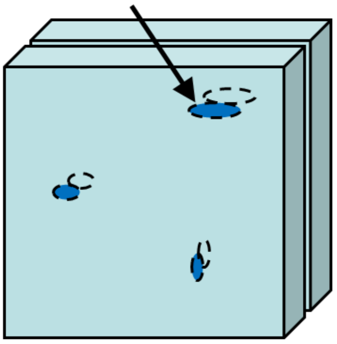

Fig. 6.17: True area of contact.

In the contact surface, solids exerts a force each other. When a force operates from a solid pushing against the other solid, the resisting force operates as the reaction of the other solid. When the object is sustained in the gravitational field, the normal force works to balance with the gravitational force (see 6.2.2).

Consider that the real contact area increases in proportion to the normal force by the deformation of the solid surface. If the friction force is proportional to the real contact area, the friction force is proportional to the normal force. In this case, coefficient of friction is constant, which is independent of the normal force (see equation (6.5)).

The interface state depends on the surroundings. The state of the solid surface in the gas depends on the atmosphere. The gas molecules are adsorbed on the surface. Molecules, such as nitrogen or oxygen, are adsorbed on the surface in the air. The water molecules are adsorbed on the surface in the humid air. The oxide film is formed on the solid metal surface by oxidation in the air (**Fig. 6.18**).

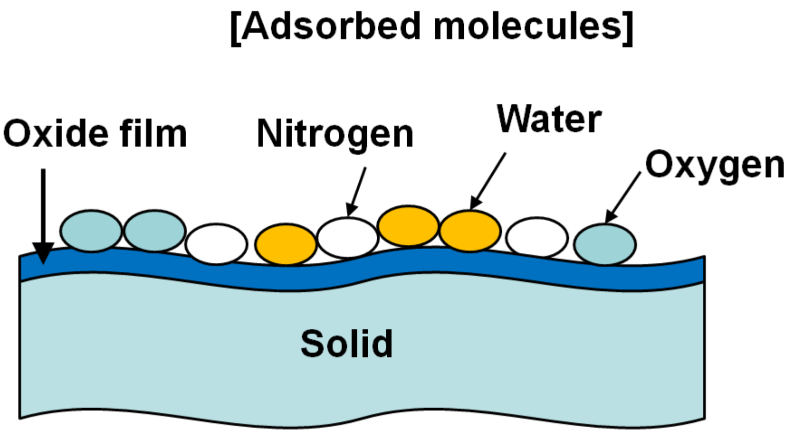

Fig. 6.18: Surface of solid.

In the vacuum, on the other hand, the adsorbed gas molecules are eliminated. When the metallic solids are pressed together in a vacuum, no adsorbing layer of gas molecules interposed between the solids. The metallic solids contact each other directly. When the real contact between the metal solids realized over the entire surface, the real contact area is equal to the apparent contact area.

The friction generates the high pressure and the heat at the local area on the interface. The high pressure and heat destroy the adsorbed layer of gas molecules and the metal oxide layer at the interface. The destruction causes the direct contact between the solids of metal. The pair of the same metals may cause fusing at the interface between the solids. The pair of the different metals is used to reduce the frictional force.

In the **roller pump** (see 7.1.1), the friction between the tube and the roller is inevitable (**Fig. 6.19**). The higher pressure for the blocking of the tube by the roller may cause abrasion of the tube.

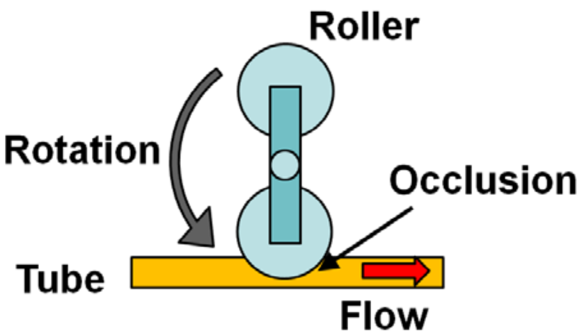

Fig. 6.19: Roller pump.

In the **screw pump**, the fluid flows through the gap between the external screw-thread (rotor) and the internal screw-thread (stator) (**Fig 6.20**). The frictional force varies with the degree of the contact between the two screw-threads, which affects the wear and the durability. The incomplete contact causes the reverse flow.

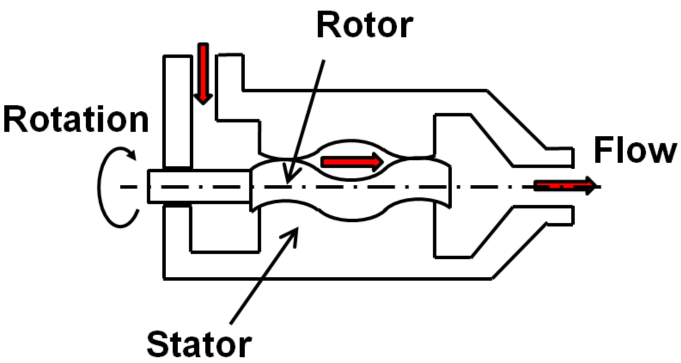

Fig. 6.20: Screw pump.

6.2.4 Surface tension and hydrophilic property

In vivo, the membrane plays an important role as the partition for the core operation of life phenomena. Therefore, it is necessary to focus on the nature of the interface. Since the biological body consists of the aqueous electrolyte solution, the affinity with the water is an index of the surface property.

The droplet of the liquid tends to become a sphere of the minimum surface area by the intermolecular force. The tension to minimize the surface area is called the **surface tension**. The unit is N m^{-1}. The surface tension of the water in the air is 72.75 N m^{-1} at 293 K.

On a solid surface in the air, a water droplet tends to become a sphere by the surface tension. When the affinity between the water and the solid surface is high, on the other hand, the water droplet is attracted to the solid surface to be deformed into a flat shape. The angle between the water-air interface and the water-solid interface is called **contact angle** θ (**Fig. 6.21**). The surface of the contact angle smaller than $\pi/2$ is called **hydrophilic** surface. The surface of the contact angle larger than $\pi/2$ is called **hydrophobic** surface.

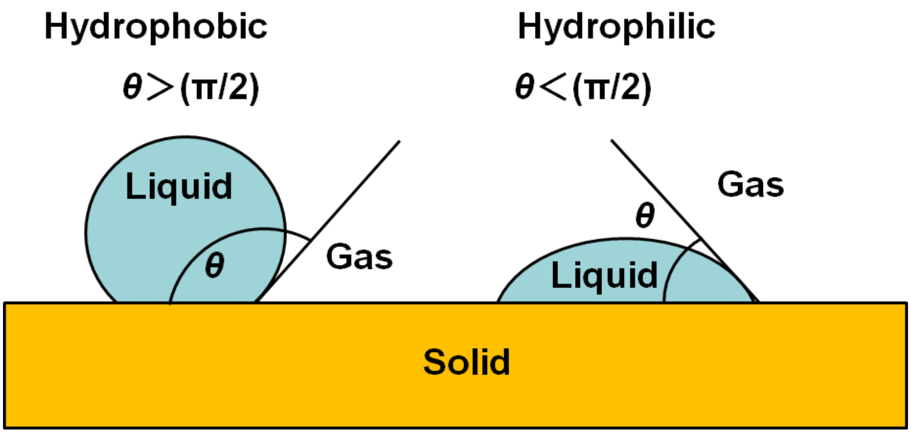

Fig. 6.21: Contact angle: *θ*.

On the water-repellent surface like polytetrafluoroethylene, the contact angle is close to π. Walls and membranes in the living body, on the other hand, are hydrophilic. The most of the surfaces, which contacts with the physiological liquid (for example, artificial walls of blood vessels), are designed to be hydrophilic.

The hydrophilic surface is noted on the cell adhesion, the platelet adsorption, and the thrombus formation. The most of cells proliferate adhering to the extracellular matrix. Thus, cells are cultured on the hydrophilic surfaces.

The blood forms **clots** by the platelet aggregation and by the coagulation proteins (**Fig. 6.22**). The clot formation is controlled by collaboration of subsystems: the **platelet aggregation**, the **coagulation** protein, and the **fibrinolysis** (**Fig. 6.23**) [24]. The clot is formed to stop bleeding, and is dissolved to recover smooth surface.

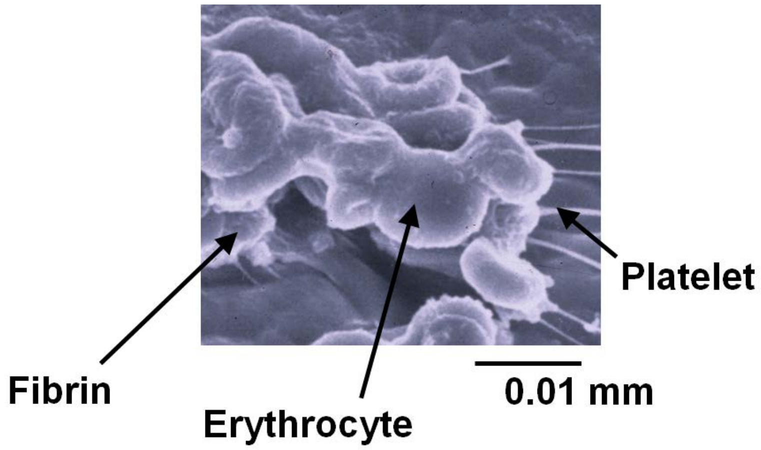

Fig. 6.22: Clot.

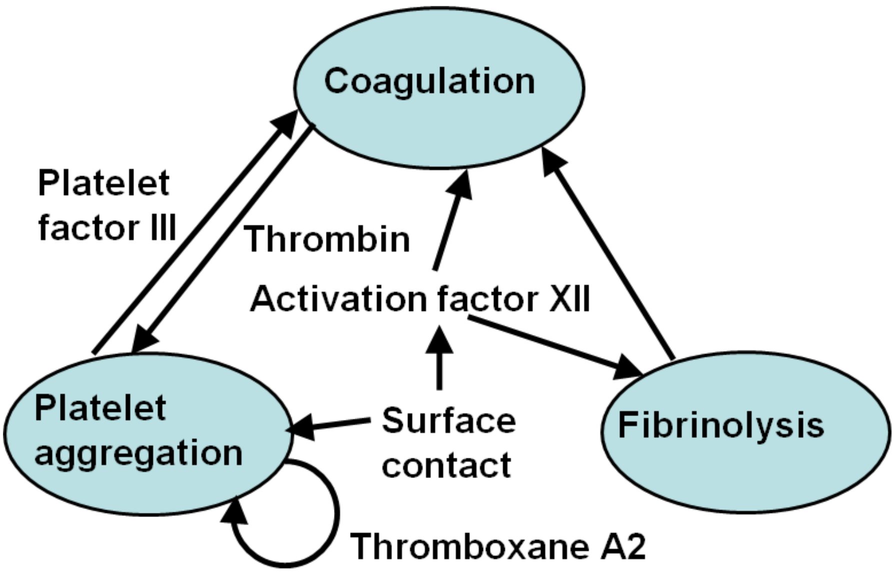

Fig.6.23: Clotting system.

The Clot plays an important role for closing the cleft of the blood vessel wall (**hemostasis**). The clot, on the other hand, prevents the flow, when it is formed inside of the vessel lumen (**thrombus**). Although the operation is necessary to connect the artificial blood vessel to the biological vessel, it makes trouble by clogging the artificial blood vessel lumen. Three-dimensional structure of biological macromolecules on the blood vessel wall might control the biological reactions.

A tube, which is inserted into a blood vessel, is called a **catheter**. The surface of the catheter is treated to prevent the clot formation. One of the methods to prevent clot formation is the coating of **heparin**, which is a biopolymer of anticoagulation.

The thrombus formation is a problem in the artificial organs, which contact with the blood. When the blood circulates in the mock circuit (**Fig. 6.24**), the clot is formed in the flow path (**Fig. 6.25**). The formation of clot can be controlled by the flow (**Fig. 6.26**).

The clot tends to be formed at the bearing of the **centrifugal** type of **artificial heart** (**Fig. 6.27**). The amount of clot can be formed in the stagnation area of the back side of the impeller (**Fig. 6.28**). The thrombus formation is controlled by the **shear rate** adjacent to the bearing of the impeller (**Fig. 6.29**).

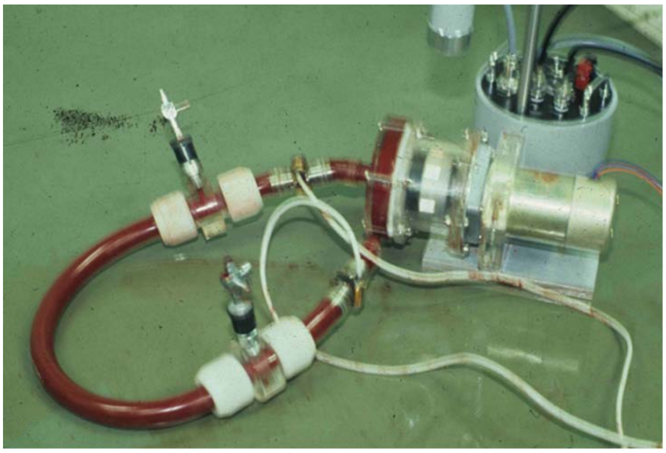

Fig. 6.24: Blood circulation circuit.

Fig. 6.25: Clot formation in tube (low flow).

Fig. 6.26: Clot formation in tube (high flow).

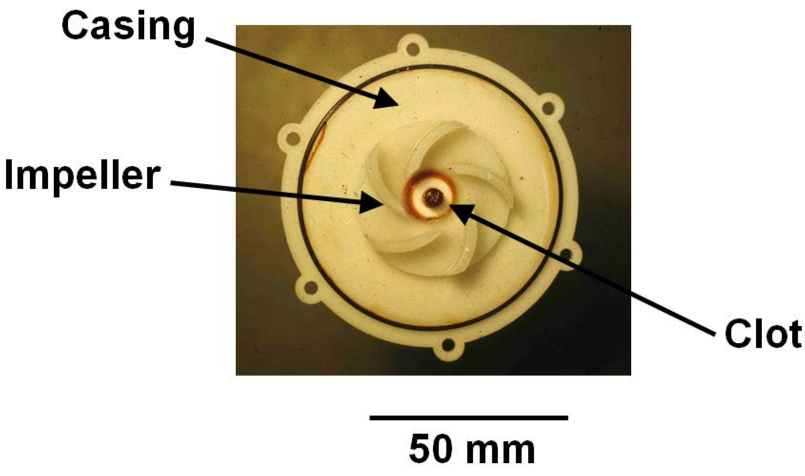

Fig. 6.27: Clot at bearing.

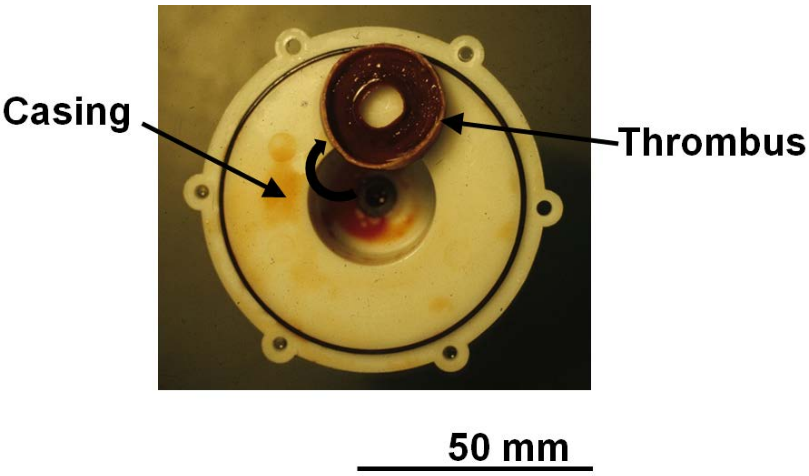

Fig. 6.28: Clot behind impeller.

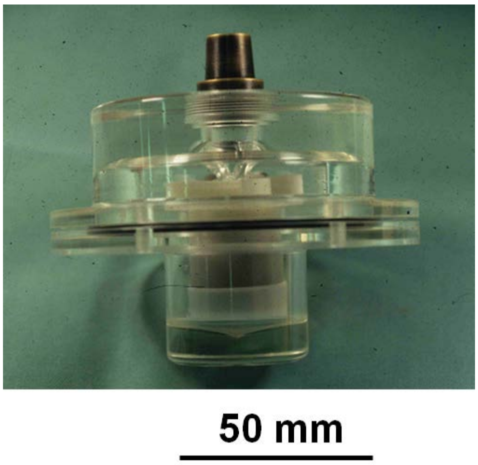

Fig. 6.29: Modified pivot of Artificial Heart.

The coating is applied on the synthetic material surface to prolong the clotting time [43]. When the blood is sheared between concave-convex cones coated with **segmented polyurethane**, clotting time is prolonged (**Fig. 6.30**) (see 4.2.4 and 4.2.6). The clots are formed in the same amount of volume as that of non-coating. The clot formation is prevented in the pulsatile flow, in which the period of low shear rate of $< 100\ s^{-1}$ is shorter than 2 s.

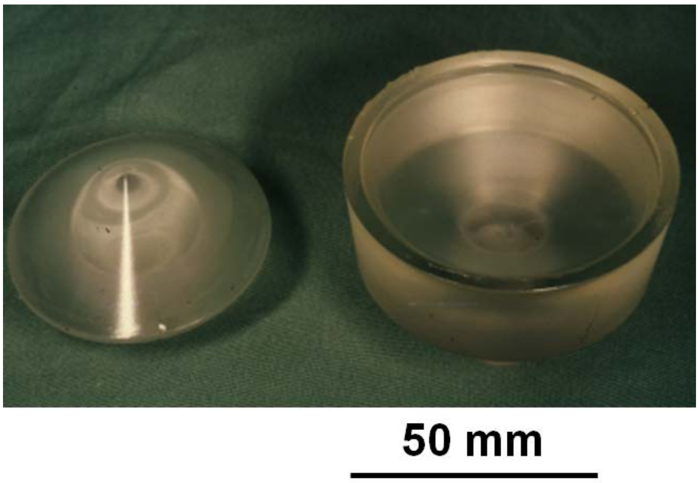

Fig. 6.30: Concave and convex cones.

6.2.5 Wear

The weight loss at the material surface by friction is called **wear**. The powder exfoliated from the base material at the wear is called the **abrasion powder**.

The volume of wear per unit slide face load and per unit slide distance is called the **comparative abrasion quantity**. Unit of the relative abrasion is $m^3 N^{-1} m^{-1}$. The degree of wear is compared by the relative abrasion. The volumes of both base objects are not always reduced by the abrasion. The volume of only one side of the base materials decreases in several cases. The volume of the base material increases, when the abrasion powders adhere to the base material.

Wear mechanisms are classified into two groups: the scraping of the surface, and the "adhesion-break". The former is called **abrasive wear**, and the latter is called **adhesive wear** (**Fig. 6.31**).

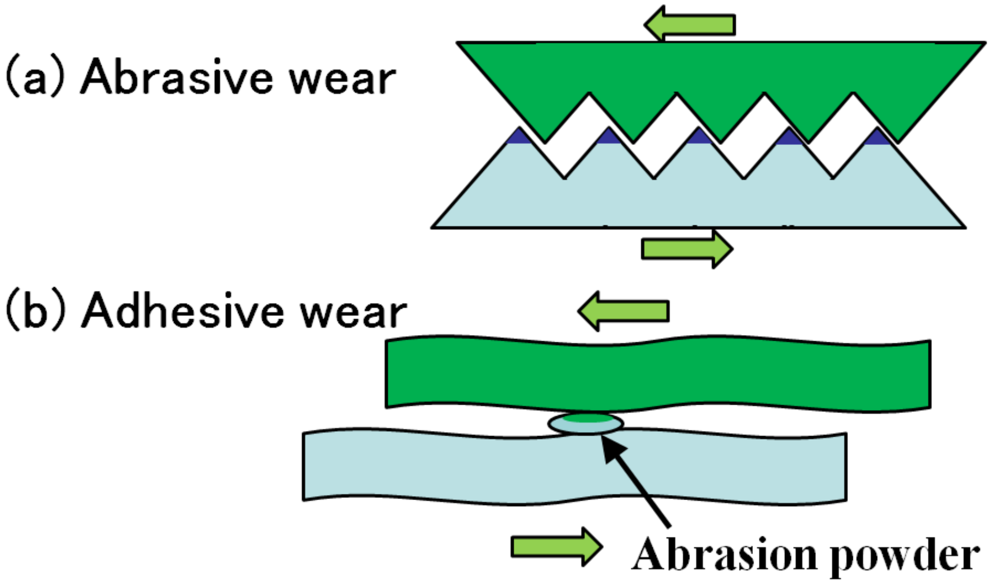

Fig. 6.31: Wear.

The friction concentrated in real contact surface raises pressure and temperature in the local area (see 6.2.3). The rise causes peeling off the adsorbed molecules and the oxide film, and the base metal surface is exposed. The chemical reaction may occur at the virgin surface. The atmosphere (gas molecules and temperature) around the friction surface affects the reaction.

At the initial friction, wear occurs due to the unstable contact (**initial wear**). At the newly formed surfaces, wear occurs due to the high reactivity (**virgin surface wear**). Wear decreases at the stable friction surface (**mild wear**) (**Fig. 6.32** (a)).

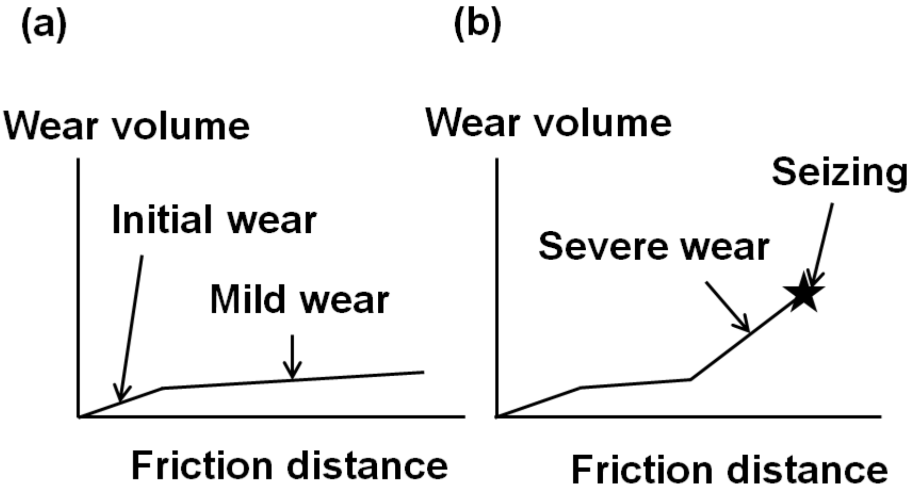

Fig. 6.32: Transition of wear.

The unstable friction surface due to fatigue modification of the material surface causes vibration, which may be accompanied with the increase of wear (**severe wear**). The friction between the wear particle and the base material cause the chipping and the adhesion. The fresh surface during the wear may sometimes cause adhesion between the base materials (**seizure**) (Fig. 6.32 (b)). The wear phenomenon includes the unstable factors.

To study on the mechanism of the wear, not only the wear volume, but also the appearance of the friction surface and the wear debris should be observed. Components of the counter base material may adhere to the friction surface. The wear debris may consist of fusion of components of the both base materials in some cases.

Both the friction and the wear are important problems on the implanted **joint prosthesis** (**Fig. 6.33**). The combination of polyethylene and stainless steel-titanium alloy is applied for the material of the sliding part. The friction affects the movement of the joint. The wear powders may cause inflammation. Ceramic is also used for the prosthesis.

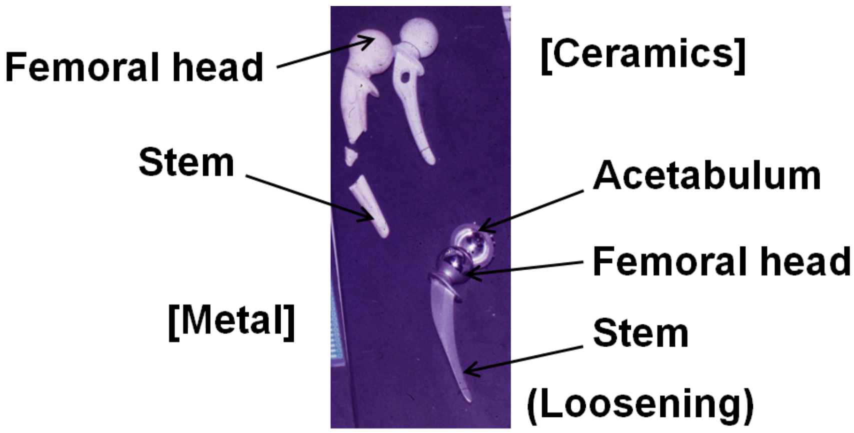

Fig. 6.33: Joint prosthesis.

Long-term fixation between the artificial joint and the bone is also a challenging problem. Against the foreign materials, the living tissue has several reactions: disassembly, isolation, and exclusion. These reactions make a gap between the living bone and the prosthetic stem (Fig. 6.23), which causes **loosening**.

A **cardiac valve prosthesis** is used to replace a heart valve. At one of the prostheses, the two valve-leaflets incline at opening to pass blood in one direction. The wear at the bearing between the **leaflet** and the **valve seat** makes malfunction of the valve (**Fig. 6.34**).

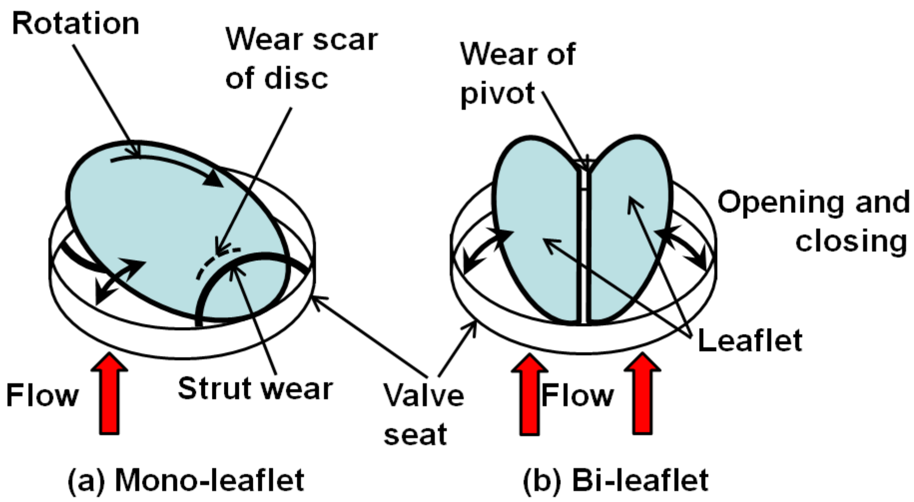

Fig. 6.34: Cardiac valve prosthesis.

The heart continues operation as a pulsatile blood pump. Valve continues operation in synchronization with the pulsation of the heart. One beat per second corresponds to the beat of 3 × 10^7 beats (60 seconds × 60 minutes × 24 hours × 365 days) in one year.

The wear at the strut or at the leaflets causes malfunction of the valve has been reported in a few cases [44]. Several metallic materials, such as nickel-chromium alloy and stainless steel, have also been used for the struts. The metallic material surface becomes unstable due to corrosion in the saline solution. The blood contains ions, and is corrosive environments.

The effect of wear debris from the valve prosthesis on the living body is not reported. This is because the volume of the wear of the prosthetic valve is small compared with that of an artificial joint.

6.2.6 Lubrication

In the relative motion between the objects, the aims of **lubrication** are as follows: reduction of frictional force, stability of friction, and reduction of the wear. Lubrication achieves the smooth movement at the joint.

The lubrication at the contact between solids is called “**solid lubrication**”. The lubrication sandwiching the fluid between solids is called “**fluid lubrication**”. The lubrication of mixture of two types of lubrication (solid lubrication and fluid lubrication) is called “**mixed lubrication**”. Substance, which is interposed at friction surface for lubrication, is called “**lubricant**”.

When fluid is sandwiched between solids, the flow resistance of the fluid governs the friction. The biological joint wrapped in the joint capsule includes the synovial fluid between the articular surfaces. When the local contact between solids occurs through the thinned synovial fluid film at lubrication surface, the frictional force becomes larger than the flow resistance of the fluid. The lubrication state is called "**boundary lubrication**".

In the human joint, the direct contact between the articular surface is prevented by several effects: drawing of the fluid by the relative movement between articular surfaces (**wedge-film lubrication**), the occurrence of pressure in the fluid by approach between the articular surfaces (**squeeze film lubrication**), and the elastic deformation of the articular surface (**Fig. 6.35**). Therefore, the frictional resistance in the human joints is much smaller than that between the solids. The fluid lubrication accompanied with the elastic deformation of the surface is called "**elastohydrodynamic lubrication**".

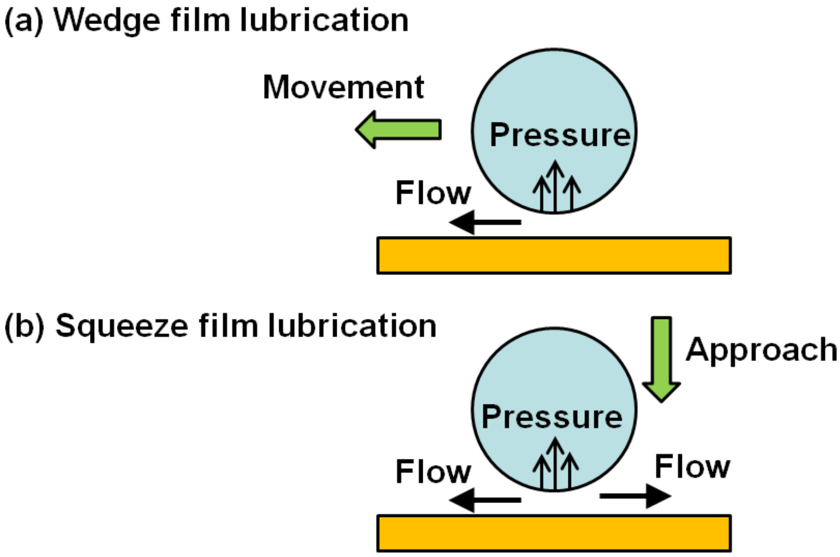

Fig. 6.35: Articular surface lubrication.

The contact between solids must be avoided to keep the fluid lubrication. The thickness of the fluid film must be kept greater than the roughness of the surface. The supply of the fluid to the friction surface must be larger than the discharge of the fluid from the friction surface. The lower viscosity coefficient of the fluid reduces the flow resistance of the fluid itself. The discharge of the fluid lubricant from the friction surface, on the other hand, decreases at the higher viscosity coefficient of the fluid.

The friction at the bearing of the rotary type of the artificial heart generates heat, which denatures the blood and causes thrombus formation (Fig. 6.19 (d)). In some rotary pumps, the shaft keeps floating from the bearing by the magnetic effect.

Questions

Q 6.1: Calculate the force applied on the hip joint in standing position by one leg at the following case: the gravitational force by body weight is 600 N, the deviation is 1 cm between the line of action of the gravity and the supporting force, the deviation is 2 cm between the line of action of the supporting force and the muscle force, and the position of the supporting force is between the gravitational force and the muscle force (see Figure 6.1).

Q 6.2: Give examples of levers to increase the force, and to reduce the force.

Q 6.3: Calculate the centrifugal force acting at the distance of 30 cm apart from the axis with rotational speed of 1000 revolutions per minute. How many times higher is it compared with the gravitational acceleration?

Q 6.4: List the type of the pressure generated in the fluid lubrication. Discuss on the lubrication in the human joints.

Q 6.5: List problems related to lubrication in the artificial heart.