Appendix A

A.1 Medical Devices and Classification

Medical device, as defined by the WHO (Medical devices: Guidance document - Classification of medical devices, n.d.) is “any instrument, apparatus, implement, machine, appliance, implant, in vitro reagent or calibrator, software, material or other similar or related article, intended by the manufacturer to be used, alone or in combination, for human beings for one or more of the specific purposes of:

- diagnosis, prevention, monitoring, treatment or alleviation of disease
- diagnosis, monitoring, treatment, alleviation of or compensation for an injury
- investigation, replacement, modification, or support of the anatomy or of a physiological process supporting or sustaining life
- control of conception
- disinfection of medical devices
- providing information for medical purposes by means of in vitro examination of specimens derived from the human body and which does not achieve its primary intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means.

According to this definition, Chloe SED fits into the definition of a medical device as it helps in control of conception.

The reason for the strict standards and regulations is due to the fact that lives are at stake. When a medical professional is using the device, they will have to trust it completely. (Team, 2019)

Classification

Medical devices are classified based on their criticality and associated risk of using the device. For CE, there are 4 classifications, Class I, IIa, IIb and III. The regulations become increasingly strict for devices of higher class. (Classification Of Medical Devices And Their Routes To CE Marking, n.d.)

Class I - Lowest perceived risk,
Class IIa - medium risk, short-term usage (<30 days)
Class IIb - medium risk, long-term usage (>30 days)
Class III - High risk

The MVA was classified as Class II (Powell & Kapp, 2019)

The Chloe SED fits under the Class IIA, as the highest classification of the system that it is a part of is IIA.

Device name	FDA	CE
Hypodermic needle	2	IIA
Spinal needle	2	IIA
Single use syringe	2	IIA
Chloe SED	1	I
Device	2	IIA

End-of-use cycle

During surgeries, there is contact between the surgical tools, other medical devices, and the patient. This contact happens at different levels, namely critical, semi-critical and non-critical. This can cause transfer of pathogens from one patient to the next, via the equipment being used, possibly leading to Healthcare Associated Infections (HAI). To prevent this, medical equipment are either disposed of after single use or reprocessed between uses to decrease risk of pathogen transfer.

There are several factors for a device to classified as a Single Use Device (SUD), or a Reusable Medical Device (RMD), namely:

Material:
SUDs are generally made using plastics, which have excellent moldability and can be used to form complex shapes. This plastic, however, is not durable and the material properties will rapidly deteriorate once used or reprocessed.

Manufacturing:
Plastics are easier to mass manufacture at a cheaper cost, hence used for manufacturing SUDs.

Reprocessing:
The material and construction of the medical device may be unable to withstand reprocessing procedures. The procedures may permanently change mechanical, physical or chemical properties of the device and leave it unsafe to be used.

Accessibility of the surfaces to be cleaned:
If the construction of a medical device does not allow thorough cleaning of it’s surfaces, the device is more likely to be designed as an SUD.

Validation and Economics:
For a device to be classified as RMD, it must be proved that the reprocessing procedure thoroughly removes all organic residue (blood, tissue) and there is no residue of the process chemicals. The validation also includes functionality and biocompatibility testing after sterilization and at the end of the device’s shelf life. This procedure costs time and money, and the manufacturer might be unable to afford, or may not want to go through (in case of small volume of products) the procedure. In this case, the devices are classified as SUD.

Waste generation:
One of the primary arguments for reusing medical devices is the amount of waste generated by disposal of SUDs.

There have been recent changes to Medical Device Regulations (MDR), to allow reprocessing of SUDs. (Massimo, 2019)

A.2 Types of sterilization methods

There are a variety of sterilization techniques (Singh et al., 2013), such as -

Steam Sterilization

Of all the methods available for sterilization, moist heat in the form of saturated steam under pressure is the most widely used and the most dependable. Steam sterilization is nontoxic, inexpensive (Adler et al., 1998), rapidly microbicidal. Like all sterilization processes, steam sterilization has some deleterious effects on some materials.

The basic principle of steam sterilization, as accomplished in an autoclave, is to expose each item to direct steam contact at the required temperature and pressure for the specified time. Thus, there are four parameters of steam sterilization: steam, pressure, temperature, and time. The two common steam-sterilizing temperatures are 121°C (250°F) and 132°C (270°F). Recognized minimum exposure periods for sterilization of wrapped healthcare supplies are 30 minutes at 121°C (250°F) in a gravity displacement sterilizer or 4 minutes at 132°C (270°F) in a prevacuum sterilizer (Table 7). At constant temperatures, sterilization times vary depending on the type of item (e.g., metal versus rubber, plastic, items with lumens), whether the item is wrapped or unwrapped, and the sterilizer type.

The two basic types of steam sterilizers (autoclaves) are the gravity displacement autoclave and the high-speed prevacuum sterilizer.

Flash sterilization

Flash sterilization is a modification of conventional steam sterilization (either gravity, prevacuum, or steam-flush pressure-pulse) in which the flashed item is placed in an open tray or is placed in a specially designed, covered, rigid container to allow for rapid penetration of steam.

"Flash" steam sterilization was originally defined by Underwood and Perkins as sterilization of an unwrapped object at 132°C for 3 minutes at 27-28 lbs. of pressure in a gravity displacement sterilizer.843 Although the wrapped method of sterilization is preferred for the reasons listed below, correctly performed flash sterilization is an effective process for the sterilization of critical medical devices.

Historically, it is not recommended as a routine sterilization method because of the lack of timely biological indicators to monitor performance, absence of protective packaging following sterilization, possibility for contamination of processed items during transportation to the operating rooms, and the sterilization cycle parameters (i.e., time, temperature, pressure) are minimal.

Ethylene Oxide "Gas" Sterilization

Exposure to the Ethylene oxide gas at a temperature between 37 to 63°C, for 1-6 hours, at a relative humidity of 40-80%. (Health, 2020)

The use of ETO (Ethylene Oxide) evolved when few alternatives existed for sterilizing heat- and moisture-sensitive medical devices.

ETO is a colorless gas that is flammable and explosive. The four essential parameters (operational ranges) are: gas concentration (450 to 1200 mg/l); temperature (37 to 63°C); relative humidity (40 to 80%)(water molecules carry ETO to reactive sites); and exposure time (1 to 6 hours). These influence the effectiveness of ETO sterilization.

The main advantage is that it can sterilize heat- or moisture-sensitive medical equipment without deleterious effects on the material used in the medical devices.

The main disadvantages associated with ETO are the lengthy cycle time, the cost, and its potential hazards to patients and staff. ETO toxicity has been established in a variety of animals, and ETO has been demonstrated to be carcinogenic.

ETO is absorbed by many materials. For this reason, following sterilization the item must undergo aeration to remove residual ETO.

Hydrogen Peroxide Gas Plasma

In Hydrogen peroxide gas plasma sterilization, the sterilization chamber is evacuated and hydrogen peroxide solution is injected from a cassette and is vaporized in the sterilization chamber to a concentration of 6 mg/l. The hydrogen peroxide vapor diffuses through the chamber (50 minutes), exposes all surfaces of the load to the sterilant, and initiates the inactivation of microorganisms. An electrical field created by a radio frequency is applied to the chamber to create a gas plasma. The excess gas is removed and in the final stage (i.e., vent) of the process the sterilization chamber is returned to atmospheric pressure. The by-products of the cycle (e.g., water vapor, oxygen) are nontoxic and eliminate the need for aeration. Thus, the sterilized materials can be handled safely, either for immediate use or storage.

The process operates in the range of 37-44°C and has a cycle time of 75 minutes. If any moisture is present on the objects the vacuum will not be achieved and the cycle aborts.

Ionizing Radiation

Sterilization by ionizing radiation is a low-temperature sterilization method that has been used for a number of medical products Because of high sterilization costs, this method is an unfavorable alternative to ETO and plasma sterilization in healthcare facilities but is suitable for large-scale sterilization. Some deleterious effects on patient-care equipment associated with gamma radiation include induced oxidation in polyethylene

Dry-Heat Sterilizers

This method should be used only for materials that might be damaged by moist heat or that are impenetrable to moist heat (e.g., powders, petroleum products, sharp instruments). It is nontoxic and does not harm the environment; a dry heat cabinet is easy to install and has relatively low operating costs; it penetrates materials; and it is noncorrosive for metal and sharp instruments. The disadvantages for dry heat are the slow rate of heat penetration and microbial killing, which makes this a time-consuming method. In addition, the high temperatures are not suitable for most materials. The most common time-temperature relationships for sterilization with hot air sterilizers are 170°C (340°F) for 60 minutes, 160°C (320°F) for 120 minutes, and 150°C (300°F) for 150 minutes.

A.3 Cleaning and Decontamination

Mechanical brushing

Chlorine solution
Concentration:140 ppm / 0.014%
Quantity : 10L

Fresh tap water
Quantity : 10 L

Soapy water
Duration : 10 mins

Running tap water

Drying

Fig. Mechanical brushing

Fig. Presept tablets

Fig. Rinsing in tap water and soapy water

Fig. Air drying

1 tin of 2.5gx100 Presept tablets - ksh 2610*

Water cost per unit (1000 L) - ksh 64†

1x520 mL bottle of Soap - ksh 350

1 Presept tablet - ksh 2.61

10L Tap water - ksh 0.64

Max 10L Tap water - ksh 0.64

Max 10mL Soap - ksh ~6.7

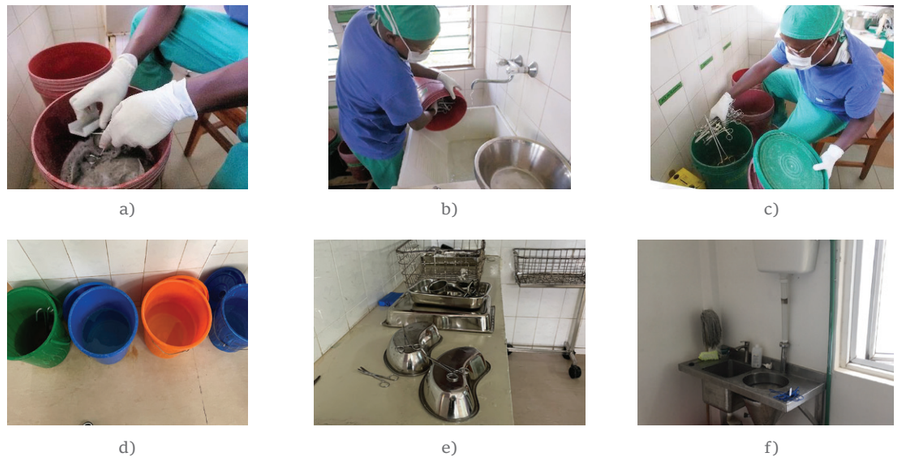
Max 10L Tap water - ksh 0.64

Costs per cycle - ksh 11.23
€ 0.087

For either sterilization or high-level disinfection to be effective, decontamination and thorough cleaning of the devices must be done first. Thus a complete cycle should include at least the following phases: pre-rinsing, cleaning, rinsing, disinfecting and drying (IPAS, 2002). In most cases in Tanzania and Kenya pre-rinsing, cleaning and again rinsing is done manually in buckets and with a regular brush.

Fig. Brush used for mechanical brushing

Following the cleaning, the devices are decontaminated by soaking in a 0.5% Chlorine solution for upto 10 mins. The devices are then removed and placed in a bucket with fresh water to rinse off the chlorine. The devices are then placed in a soapy water solution to neutralize any remaining chlorine. Once this is done, the devices are rinsed under running tap water, and air dried before the next sterilization process.



a) b) c) d) e) f)

Fig. Process of sterilization in Tanzania

*Taken from hospital purchasing records of Nyanza Reproductive Health Society(NRHS)

†Nairobi City Water and Sewerage Company. (2021). Water Tariffs. Nairobi City Water and Sewerage Company. https://www.nairobiwater.co.ke/water-tariffs/

Sterilisable and autoclavable medical grade plastics | Ensinger. (2021). https://www.ensingerplastics.com/en/shapes/plastic-material-selection/sterilisable-autoclavable

A.4 Steam sterilization

Preparation

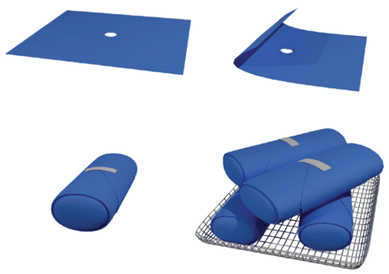


Fig. Illustration of the packing process

Fig. Packing of medical devices in sterilization cloth

50m Autoclave tape - ksh 300*
Power cost - ksh 24.65/KWh†
20L of distilled water - ksh 656*

Procedure

Fig. From left a) Packing within the autoclave
b) running the autoclave

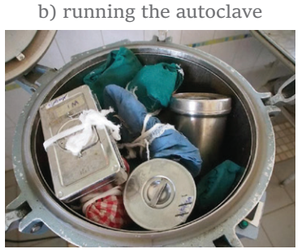


Fig. Packing within the autoclave

~20 cm autoclave tape - ksh 1.2
Autoclave tape cost for ~4 sterile wraps - ksh 4.8

Storage

Fig. From left a) Autoclave tape with pattern after successful procedure
b) storage of sterilized devices

7L Distilled water - ksh 229.6
1 cycle of 45 mins power consumption - 3.375 KWh
Cost - ksh 83

Costs per cycle - ksh 317.4
€2.51

Of all the methods available for sterilization, moist heat in the form of saturated steam under pressure is the most widely used and the most dependable. Steam sterilization is nontoxic, inexpensive (Adler et al., 1998), rapidly microbicidal. Like all sterilization processes, steam sterilization has some deleterious effects on some materials.

The basic principle of steam sterilization, as accomplished in an autoclave, is to expose each item to direct steam contact at the required temperature and pressure for the specified time. Thus, there are four parameters of steam sterilization: steam, pressure, temperature, and time. The two common steam-sterilizing temperatures are 121°C (250°F) and 132°C (270°F). Recognized minimum exposure periods for sterilization of wrapped healthcare supplies are 30 minutes at 121°C (250°F) in a gravity displacement sterilizer or 4 minutes at 132°C (270°F) in a prevacuum sterilizer (Table 7). At constant temperatures, sterilization times vary depending on the type of item (e.g., metal versus rubber, plastic, items with lumens), whether the item is wrapped or unwrapped, and the sterilizer type.

The process of steam sterilziation in context was explored. A set of medical devices are first packed into a sterilization cloth. The package is sealed with autoclave tape and the date of the sterilization is marked. The packages are placed in the autoclave tray and the autoclave cycle is run. A large sliding door autoclvae consumes about 7L of distilled water per cycle. Once the cycle is complete, the door is opened and the packages are allowed to cool. They are then removed and placed in shelves.

*Taken from hospital purchasing records of Nyanza Reproductive Health Society(NRHS)

†Nyawira, S. (2021, October 27). Kenya's electricity cost fourth highest in Africa, study shows. The Star. https://www.the-star.co.ke/business/kenya/2021-10-27-kenyas-electricity-cost-fourth-highest-in-africa-study-shows/

A.5 Chemical Sterilization

Fig. Glutaradehyde solution

Fig. Rinsed under running distilled water

Fig. Ascpetic packaging

5L of 50% Glutaraldehyde solution - ksh ~7166*
Water cost per unit (1000 L) - ksh 64
20L of distilled water - ksh 656*

200mL of 50% Glutaraldehye solution† - ksh ~284.64
5L Tap water - ksh 0.32

~3L Distilled water - 98.4 ksh

Costs per cycle - ksh 383.36

Liquid chemical sterilization is a procedure used to sterilize devices which are made out of materials that are not heat resistant. It is a two part procedure, first the device is cleaned with a chemical, and second the device is rinsed with running water to remove any chemical residue. It is not possible to ensure sterility after rinsing with water, so this procedure is only recommended for devices that cannot be steam sterilized or are incompatible with other sterilization methods such as gas/vapor/plasma or low temperature process. (FDA, 2018)

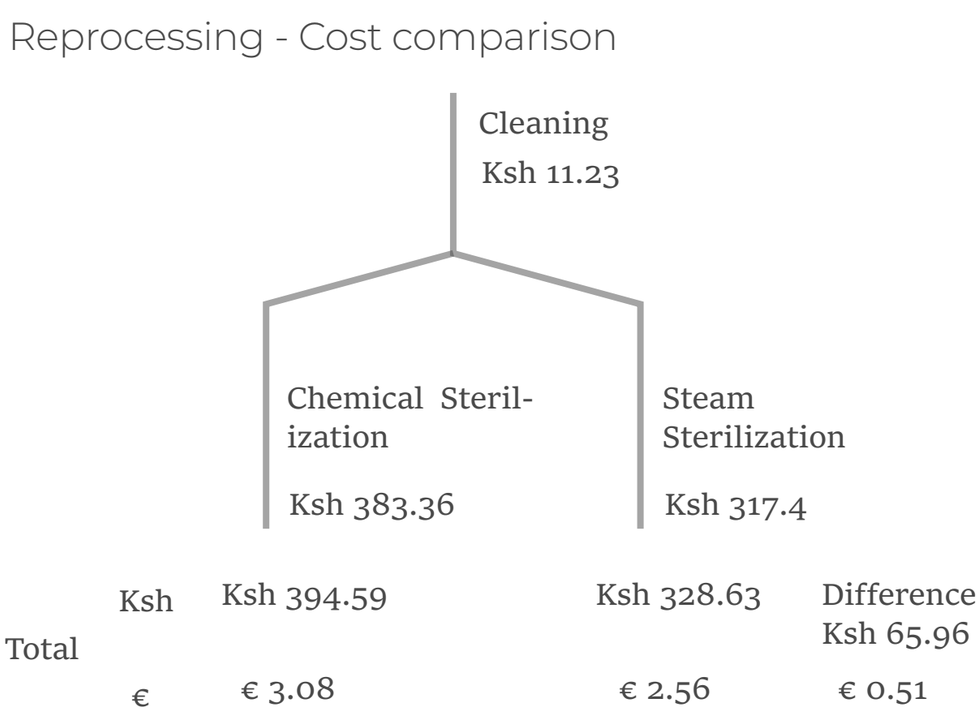
The process of Liquid Chemical Sterilization was explored. A bath of the liquid agent, in this case 2% Glutaraldehyde is prepared. The devices to be sterilized are placed inside and the contianer is sealed with an airtight lid.

This solution is allowed to rest for 10hours, as per the recommended time. At the end of this time, the lid is removed and the sterilized devices are removed using clean steel foreceps or gloved hand. These devices are then rinsed under running distilled water, and then allowed to airdry or is dried with a sterile towel/guaze. Once dry, they are packed asceptically into sterile bags. It is recommended to use these sterile devices withing 7 days, or it has to be sterilized again before use.

*Taken from hospital purchasing records of Nyanza Reproductive Health Society(NRHS)

†PhysiologyWeb. (n.d.). Dilution Calculator - Molarity, Percent - PhysiologyWeb. Copyright © 2000-2019 PhysiologyWeb. Retrieved October 7, 2021, from https://www.physiologyweb.com/calculators/dilution_calculator_molarity_percent.html

A.6 Cost comparison of sterilization methods



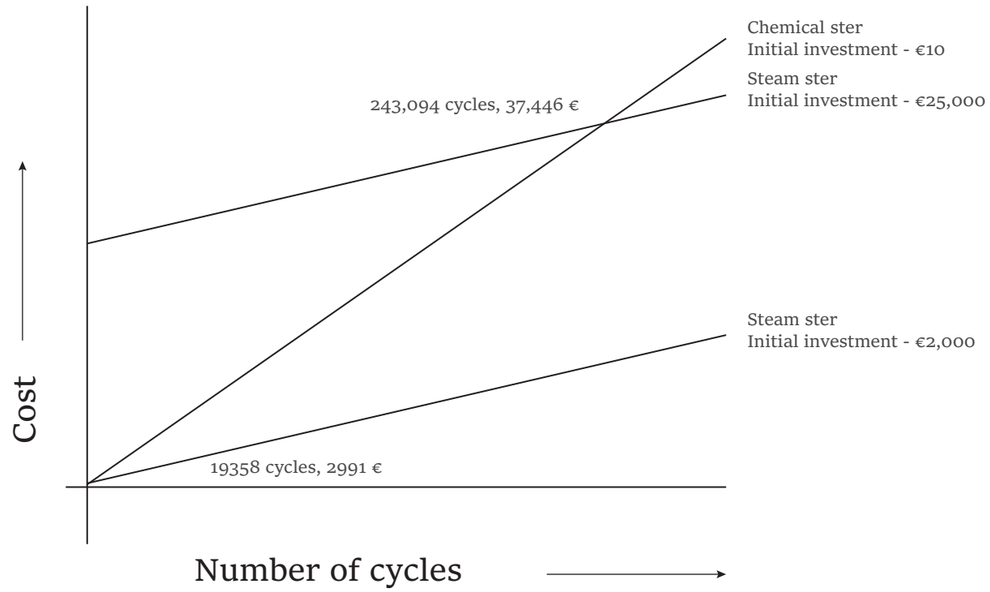
The cost of each cycle of sterilization comes upto €3.08 per cycle of Chemical sterilization and €2.56 per cycle of steam sterilization. But this value does not speak about the individual cost of reprocessing each SED unit. For this, the cost will have to be divided by the total number of devices that are being sterilized. A 'unit' of medical devices are used and sterilized together. The contents of the unit is on table xx.

During steam sterilization, a total of 4 wraps are sterilized at the same time. Each wrap contains one unit of devices. Therefore, the total cost of sterilizing one device is even lower.

Cost of reprocessing Chloe SED for x number of cycles

Number of cycles		10	25	50	100
Chemical sterilzation	ksh	198.94	497.34	994.69	1989.38
	€	1.54	3.85	7.7	15.4
Steam sterilzation	ksh	41.34	103.34	206.69	413.38
	€	0.32	0.8	1.6	3.2

Althought the running cost of Steam sterilization is 5 times cheaper than chemical sterilization, for chemical the initial investment is for the airtight containers, which would amount to < 10 €. Whereas, for Steam sterilization, the cost of the autoclave can range anywhere from 500 € to 30,000 €, based on the type, manufacturer of the autoclave and the amount of donations received. Due to this difference in capital, steam sterilization becomes cheaper after a certain cycles of use, based on the initial investment, as shown below



A.7 Future categorization of healthcare in Kenya

Level 1 - Community facilities are run by certified medical clinical officers. This, along with Level 2 provide a first line contact: provision of preventive healthcare services. They offer some of the services such as treatment of minor ailments like diarrhea, tuberculosis (TB) screening, home visits, contact tracing of TB patients and tracing of TB defaulters, screening of malnutrition, malaria rapid test, blood pressure and blood sugar testing, HIV testing and health talks with pregnant women and observations of signs of danger.

Level 2 - Health dispensaries are run by clinical officers. This, along with Level 1 provide a first line contact: provision of preventive healthcare services. In addition to the facilities offered by Level 1 hospitals, they offer services such as outpatient services, VCT services, laboratory Services, well baby Clinics, antenatal and postnatal services, pharmacy, counseling services, curative treatment.

Level 3 - Health centers are small hospitals with minimal facilities. They are run by at least one doctor, clinical officers and nurses. In addition to the facilities offered by Level 2 hospitals, they offer services such as maternity in-patient services with a ward, diabetes & hypertension clinics, and comprehensive care clinics for patients living with HIV.

Level 4 - Primary care facilities for Counties are run by a director who is a medic and at best a doctor by profession. The facilities offered are the same as level 3 hospitals, plus x-ray services. These facilities number over 110 in Kenya as of 2021.

Level 5 - Kenya's 47 counties, and each county has at least one secondary referral hospital. They are run by Chief Executive Officers who are medical professionals and have over a 100 bed capacity. There are a total of 68 country referral hospitals as of 2021.

Level 6 - National referral hospitals provide the same range of services as Level 5 hospitals, but also offer specialized treatments to patients. There are only 6 in the country.

According to Kenya Health Policy 2014 – 2030 , the government aims to make policy changes in line with the constitution of Kenya and global health commitments. One of the changes the policy aims to accomplish is the decentralization of healthcare. By the end of the policy, healthcare facilities are organized into 4 levels.

In essence, the decentralized system has consolidated service areas into 4 main categories for ease of governance and responsibility. These responsibilities are shared between the national government and county governments.
Level 1: Community health services.

Level	Hospital
1	Community health services
2	Primary care services
3	County referral services
4	National referral services

This level comprises all community-based demand creation activities, that is, the identification of cases that need to be managed at higher levels of care, as defined by the health sector.

Level 2: Primary care services. There are the dispensaries, health centers and maternity homes for both public and private providers.

Level 3: County referral services: These are hospitals operating in and managed by a given county and consist of the former level four and district hospitals in the county and include public and private facilities.

Level 4: National referral services: This level comprises facilities that provide highly specialized services and includes all tertiary referral facilities.

A.8 Pain scale rating

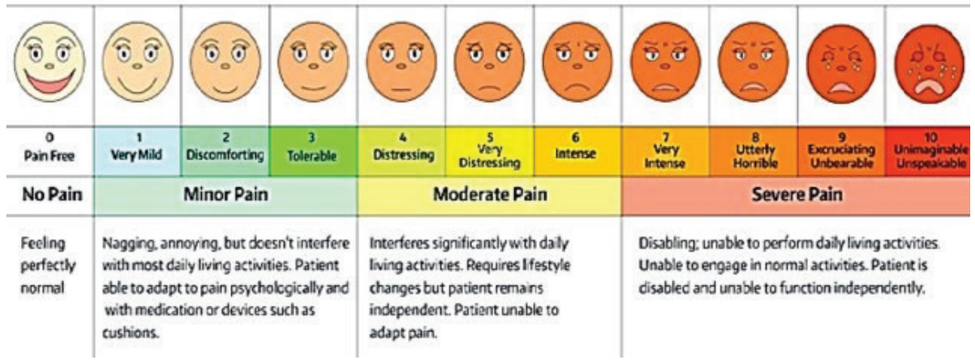


Fig. Pain scale rating (Aby, 2019)

A.9 Kinds of abortions

Abortion pill (Early medical abortion)
After an ultrasound to ensure pregnancy is early and not ectopic (pregnancy is fallopian tubes), the patient takes mifepristone, followed by misoprostol after 24 hours. Products of conception are pushed out between 30 minutes to 24 hours after the pill is taken.

This method is effective within the first 10 weeks of pregnancy. The pain, bleeding and cramping associated with this procedure is similar to period cramps, and over-the-counter medication is usually sufficient to help with the pain.

Vacuum Aspiration

A thin tube connected with a handheld syringe will be inserted into the uterus through the cervix, and vacuum is used to remove the products of conception. This can be done manually, Manual Vacuum Aspiration, or using a mechanical pump, known as Electric Vacuum Aspiration or just Vacuum Aspiration.

This method can be used within 3 to 12 weeks of pregnancy. After the procedure is completed, there may be irregular bleeding for up to 2 weeks. Cramps, similar to those in menstrual cycle, may be present for up to a few days before the uterus recovers.

Dilation & Curettage (D&C)

During D&C, the cervix is dilated and a curette, a metal rod with a handle on one end and a loop on the other, is then inserted into the uterus through the dilated cervix. The curette is used to gently scrape the lining of the uterus and remove the tissue in the uterus.This can be combined with suction, using a plastic suction curette to remove products of conception.

This procedure can be done between 2 to 12 weeks of pregnancy. The procedure can involve some pain and discomfort. Similar to Vacuum Aspiration, after the procedure is completed, there may be irregular bleeding for up to 2 weeks. Cramps, similar to those in menstrual cycle, may be present for up to a few days before the uterus recovers.

Dilation and Evacuation (D&E)

Similar to D&C, D&E also involves the use of other instruments (such as forceps) along with suction to empty the uterus. The cervix will have to be dilated wider than when D&C is performed. Because of this the cervix will have to be softened and dilated ahead of time. This process may take a few hours.

This procedure can be performed during the second trimester (between 13 to 24 weeks of pregnancy). As this procedure can be painful, stronger pain medication may be used, in addition to local anesthetic.

Labor Induction (aka Induced abortion)
As the name implies, induction abortion involves medications that cause (induce) the uterus to contract and expel the pregnancy. The patient will be given strong medications for pain and sedatives.

This procedure is generally done when the pregnancy is over 24 weeks. Induced abortion feels similar to labor. Painful contractions can last for up to a day.

Hysterectomy

A hysterectomy is performed in a manner similar to a C-Section. A surgical incision is made through the abdomen into the uterus to remove uterine contents.

This procedure is generally done when the pregnancy is over 24 weeks. This surgery is performed under general anesthetic or a local anesthetic which numbs the entire lower part of the body. It is considered as last resort for an abortion method.

A.10 Plastics as disposable medical devices

An advantage offered by plastics is the ability to create single-use, disposable products for very low cost. With a rise in infectious diseases globally and increased concerns about cross-contamination, disposable plastic products are become the first choice by large portions of medical professionals. This choice is further affirmed by a rise in shorter hospital stays and home health care.

Some reasons for the shift towards plastics are:

Increases in infectious diseases that result in increased usage of disposable products
The shifting of health-care payments from individual physicians and hospitals to health maintenance organizations (HMOs), nursing facilities, and centralized purchasing, and an increase in home health care
Changes in medical device sterilization technologies—The use of high-energy gamma radiation and e-beam sterilization continues to increase over the use of ethylene oxide, steam, and autoclave methods
More emphasis on environmental regulations and the use of biodegradable materials
Changes in (FDA/European Union/regional) health-care regulations
The trend toward “defensive medicine,” primarily due to increased liability lawsuits and the need for product safety
New technologies, like diagnostic imaging and laser surgery, implants, and hip replacements, that require polymers with improved biocompatibility properties
The continued drive toward industry cost-containment policies

A.11 Necessary characteristics of plastics

As introduced in Chapter 3.1 pg. 25., materials used in medical devices must adhere to a list of necessary characteristics. These characteristics are explored below.:

Sterilization resistance

There are two main factors that have to be considered when looking at the sterilization of plastics: softening point and hydrolytic stability.

Softening point is the temperature at which a material softens beyond some arbitrary softness and begins to lose its form. ('Softening Point', 2021) Plastics with lower softening points are susceptible to warping and deformation by sterilization processes, so the preference is for plastics with higher softening points.

Hydrolytic stability is defined as the resistance of a cured polymer material to reverting to a semisolid or liquid form when exposed to high humidity and temperature. Therefore, materials that have lower heat distortion temperatures are preferred, as they are less prone to hydrolysis. Materials with higher heat distortion points, such as polycarbonate, polyesters and polyamides, are unable to handle steam sterilization, and can only go through a few steam-sterilization cycles.

Sometimes products that have a higher softening temperature than the autoclaving temperature can warp or distort due to the release of molded-in stress (BEN DALY et al., 1998). Molded-in stress is caused by the rapid cooling or improper design of the part. Heating the part relieves the molded-in stress, causing differential stress and hence deformation. Where autoclaving is to be used, the effect of multiple sterilization cycles needs to be considered to prevent the cumulative effects of the treatment on the plastic.

Most plastics will survive 1-5 cycles of steam sterilization. For reusable devices that need up to 100 sterilization cycles, polysulfones, polyether sulfones, polyetherimides, polyether ether ketone (PEEK), and liquid crystal polymers (LCPs) are generally used.

Chemical resistance

Medical devices typically come into contact with various solvents and chemicals, both during manufacturing and end-use. Any plastic used in its manufacture must thus maintain its integrity, performance, and appearance when exposed to such solvents and chemicals.

Crystalline plastics typically display higher chemical resistance than amorphous materials, since the latter is more porous and has a higher tendency to absorb liquids and solvents. They are also prone to molded-in stress during processing, making them susceptible to environmental stress cracking when exposed to chemicals.

Amorphous plastics tend to be less chemically resistant than crystalline materials as they absorb liquids or solvents more easily (Mark, 2014). They are also prone to molded-in stress during processing thus making them more susceptible to environmental stress cracking when they are exposed to chemicals.

Leachables and Extractables

Another important point to consider while choosing a material for use in medical devices are the materials that are leached out or extracted from the plastic when in contact with chemicals, reagents, or bodily fluids during use cycles. This is especially important for combination products where drugs come into extended contact with plastic containers and fluid delivery systems (FDA, 2021).

Extractables are compounds that can be extracted from the elastomeric components or coatings of the container closure system when in contact with solvents at various temperatures of use and storage.

Leachables are compounds that leach or migrate into the drug or fluid from the elastomeric or plastic components or coatings of the container and closure system, as a result of direct contact with the drug or fluid.

Biocompatibility

Biocompatibility is defined by the reaction of a material when it comes in contact with skin, tissues, or biological fluids for defined or extended periods of time. Materials that have no effect on the composition, function or safety of the patient's biological systems are biologically compatible. This is typically defined by the nature and composition of the material, the design of the device, the nature of contact with the patient, and the duration and temperature during contact.

Shelf Life and Aging

Material aging information, including physical, thermal, and optical performance over time, is a key variable to consider for ensuring product integrity to meet validation requirements including evidence of sterility and fitness for use over a product's life cycle. Aging tests at elevated temperatures and shorter periods of time can simulate long-term aging (Micom Laboratories, 2022).

Joining and Welding

Finished medical devices need to be assembled together and in some cases, several parts and components might be required. In the case of Chloe SED, the product has to be assembled and disassembled several times within its lifetime. Several joining techniques can be used, including mechanical methods, heat and friction methods, solvents and adhesives.

Mechanical techniques
Two major methods exist for mechanical joining - fasteners such as screws, bolts, and rivets, and interference fits such as snap-fit and press-fit techniques.

Solvents like MEK (Methyl Ethyl Ketone also known as Butanone) and THF are used in the joining of plastics.

A.12 Types of Plastic manufacturing methods

3D Printing:

3D printing is the technique of building material layer by layer to form the part/product. It is a time consuming method (with current technology) with minimal tooling cost. Lead time is high and varies based on the volume and complexity of the part to be printed, but can be upto multiple hours for large parts.

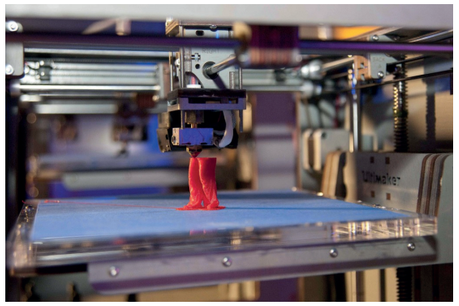


Fig. A complex form being 3D printed. (Image credit: Science museum)

CNC Machining:

CNC machining is a subtractive method of manufacturing, where the process starts with blocks of plastics and material is removed to form the product. There is a high amount of material scrap that is generated. The procedure is generally very expensive and used for high-precision applications that require tight tolerances and are difficult to mold.

Fig. Plastic CNC machining (Image credit: Starlight Fabrication & Solutions)

Rotational Molding:

A heated hollow mold is filled with powdered thermoplastic and roasted along 2 axes. This method of production is great for manufacturing large hollow parts. The setup cost for tooling is high but the manufacturing cost per unit is low.

Fig. Rotational moulding of a large plastic product (Image credit: Global Rotomoulding)

Vacuum Forming:

A plastic sheet is heated and formed around a cast using a vacuum. The vacuum forces the plastic to take the shape of the cast. The manufacturing method is limited to thin plastics and geometries.

Fig. x.x. Vacuum forming of a plastic product (Image credit: Formlabs)

Injection Molding:

Injection molding works by injecting molten thermoplastic into a mold under pressure. The material for the mold is decided based on the number of units that needs to be produced, with hardened steel lasting longer than aluminum molds. The cost of the mold is also based on the complexity of the part that is being formed. The machine requires a high investment to set up but it is the cheapest option for high volume production.

Fig. x.x. Injection mould and parts (Image credit: MSI)

Blow molding:

Blow molding uses air to inflate a heated plastic tube to fill the shape of the mold. This method is commonly used to manufacture hollow parts, such as plastic bottles.

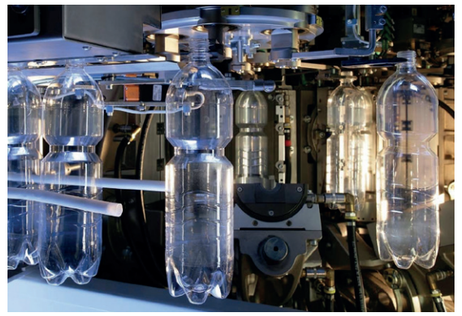
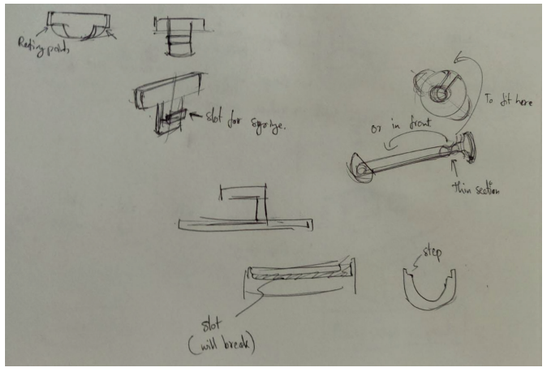
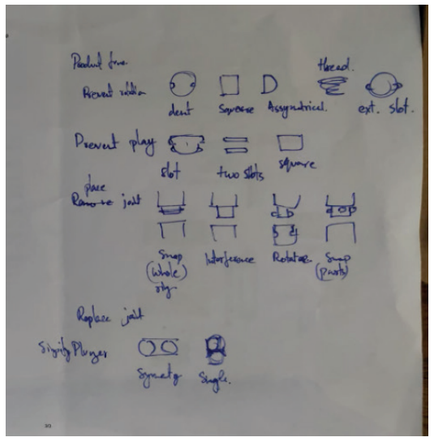
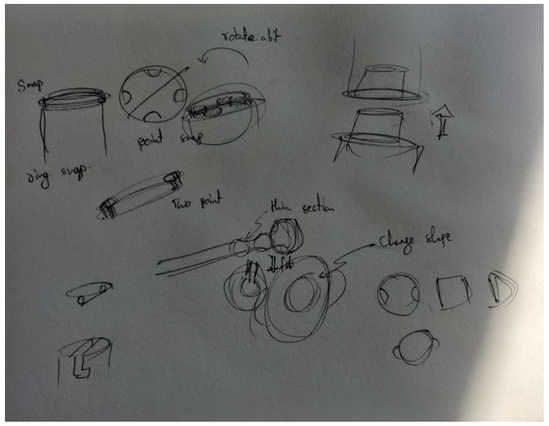


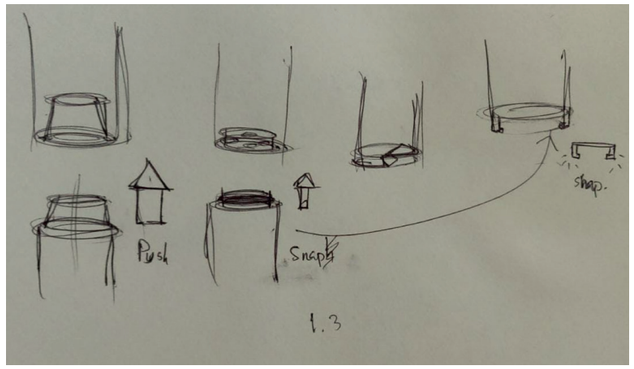
Fig. x.x. Blow molding of plastic bottles (Image credit: Bionique)

A.13 Ideation









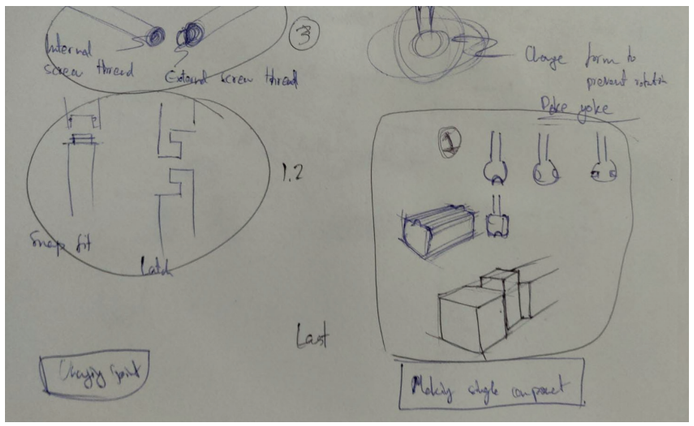


Fig. x.x. Concept generation sketches

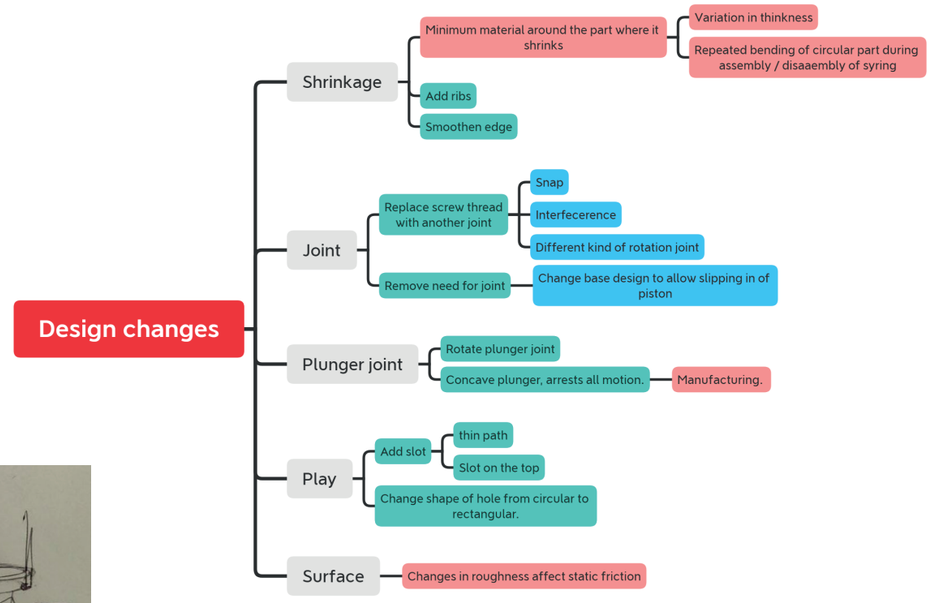


Fig. x.x. Design changes and possible solutions

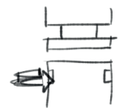
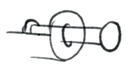
Replace joint	 Snap fit	 Rotation joint	 Complementary shapes	 Compliant joint
Remove joint	 Assemble during mfg	 Remove material	Replace with simpler materials	 Change shape of plunger

Fig. x.x. Morphological chart

A.14 Injection moulding

Injection moulding is a manufacturing process for producing parts by injecting molten material into a mould. Material for the part is fed into a heated barrel, mixed (using a helical screw), and injected into a mould cavity, where it cools and hardens to the configuration of the cavity.

Injection moulding is the most common modern method of manufacturing plastic parts; it is ideal for producing high volumes of the same object.

Injection moulding uses a special-purpose machine that has three parts: the injection unit, the mould and the clamp. Parts to be injection-moulded must be very carefully designed to facilitate the moulding process; the material used for the part, the desired shape and features of the part, the material of the mould, and the properties of the moulding machine must all be taken into account. The versatility of injection moulding is facilitated by this breadth of design considerations and possibilities.

Moulds are generally made from tool steels, but stainless steels and aluminium moulds are suitable for certain applications. Aluminium moulds are typically ill-suited for high volume production or parts with narrow dimensional tolerances, as they have inferior mechanical properties and are more prone to wear, damage, and deformation during the injection and clamping cycles; however, aluminium moulds are cost-effective in low-volume applications, as mould fabrication costs and time are considerably reduced.[1] Many steel moulds are designed to process well over a million parts during their lifetime and can cost hundreds of thousands of dollars to fabricate.

Stages of Injection moulding

Plastic injection moulding processes consist of four main stages: filling, packing, cooling and stripping. The four stages determine the quality of the injection moulded parts, and the four stages are a complete and continuous process.

Filling stage

Filling the melt flow into mould cavities is the first step in the process, the mould cavities would be filled about 95% in this stage. Generally, the shorter filling time, the higher the moulding efficiency, but in practice, the injection moulding time or speed is influenced by many other factors, namely, the viscosity of the material flow, injection pressure, setting the injection speed (the faster the reaction the greater), runner, gate friction loss, venting, mould structure, and Mould temperature setting.

Packing stage

The holding pressure is continuously applied in the packing stage, the melt compacted to increase the density of the plastic (densification) to compensate for the plastic shrinkage behaviour. In the packing process, pressure in the mould cavity is high because it's almost full. Injection moulding machine screws are still moving forward slightly, plastic flow rate becomes very slow, in the packing stage, plastic mould wall is cooled down and solidified until the gate is closed.

Holding pressure and speed is usually 50% to 65% of the maximum pressure and speed of filling, which means holding pressure is 0.6 ~ 0.8 MPa lower than the injection pressure.

Cooling stage

The design of the cooling system of a injection mould is very important. Because the moulded plastic article to need to be cooled and solidified to avoid deformation or damage. The cooling time of the takes about 70% to 80% of injection moulding cycle, so a well-designed cooling system can shorten the moulding time and improve the productivity magnificently. Poorly designed cooling systems will extend moulding time, increase costs; uneven cooling will cause deformation of plastic parts.

Releasing stage

The last process of plastic injection moulding is releasing the parts from mould cavities, it's also called de-moulding. Even the plastic parts have been cooled down and solidified during the cooling stage, but you still need to be careful about the way of releasing them. Un-proper ways will deform the plastic moulded parts or even cause damage. There are two common methods of releasing, injector and stripper plate, which way to go depends on the moulded plastic parts structure. Ejector layout should be uniform to achieve stable releasing. Preferable location of ejector is where there is maximum strength and largest release resistance on the part. The stripper is generally used for deep cavity thin-walled containers or transparent products with no ejector mark allowed.

Chloe SED User test

What version of the Chloe SED is currently being discussed about?

Old design (Version

It was easy to figure out the assembly of the body and plunger

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

It was easy to figure out the assembly of the SED and syringe

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The plunger/thumbpress of the SED feels sturdy during use

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The assembly between the syringe and SED feels sturdy during use

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

The rotation of the thumbpress along it's axis is noticeable

	1	2	3	4	5	
Completely disagree	○	◉	○	○	○	Completely agree

The mechanical play of the thumbpress during use is noticeable

	1	2	3	4	5	
Completely disagree	○	◉	○	○	○	Completely agree

It was easy to figure out the disassembly of the body and plunger

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

It was easy to figure out the disassembly of the SED and syringe

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The assembly process is time consuming (>1 min)

	1	2	3	4	5	
Completely disagree	○	○	◉	○	○	Completely agree

The disassembly process is time consuming (>1 min)

	1	2	3	4	5	
Completely disagree	○	○	◉	○	○	Completely agree

It is easy to withdraw anesthesia into the syringe while using the SED

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The parts of the SED seems easy to misplace during use and reprocessing

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The parts of the SED looks easy to rinse and dry

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The parts of the SED looks easy to clean

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

Chloe SED User test

What version of the Chloe SED is currently being discussed about?

Redesign (Version 3)

It was easy to figure out the assembly of the body and plunger

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

It was easy to figure out the assembly of the SED and syringe

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

The plunger/thumbpress of the SED feels sturdy during use

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

The assembly between the syringe and SED feels sturdy during use

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

The rotation of the thumbpress along it's axis is noticeable

	1	2	3	4	5	
Completely disagree	◉	○	○	○	○	Completely agree

The mechanical play of the thumbpress during use is noticeable

	1	2	3	4	5	
Completely disagree	◉	○	○	○	○	Completely agree

It was easy to figure out the disassembly of the body and plunger

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

It was easy to figure out the disassembly of the SED and syringe

	1	2	3	4	5	
Completely disagree	○	○	○	○	◉	Completely agree

The assembly process is time consuming (>1 min)

	1	2	3	4	5	
Completely disagree	◉	○	○	○	○	Completely agree

The disassembly process is time consuming (>1 min)

	1	2	3	4	5	
Completely disagree	◉	○	○	○	○	Completely agree

It is easy to withdraw anesthesia into the syringe while using the SED

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The parts of the SED seems easy to misplace during use and reprocessing

	1	2	3	4	5	
Completely disagree	◉	○	○	○	○	Completely agree

The parts of the SED looks easy to rinse and dry

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree

The parts of the SED looks easy to clean

	1	2	3	4	5	
Completely disagree	○	○	○	◉	○	Completely agree