final report

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3D printing demonstration

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Executive summary

Food 3D printing appears to be primarily paste printing with most of this relying on the viscous nature of the food to hold shape prior to further cooking or use, meat ink being the same. The only products that currently employ a 'setting/fixing phase' is chocolate and sugar, which both employ crystallisation (chocolate with fat).

It is highly likely that meat could be 'fixed' as discussed in V.RMH.0034, the Queensland University report (Godoi and Sangeeta) using its natural constituents. An alternative maybe to add a thickening agent (around 0.2% w/w) or using a blended gum like alginate and lightly misting a calcium chloride solution over the printed material, fixing it within a few seconds. These options do not eliminate the issue of needing to screen the material, which is the current substantial bottleneck in preparing 3D printed meat ink.

The solution may be to print with larger nozzles and being smart about the designs utilised. Benefits of doing this are that it substantially reduces the 3D printing time while reducing blockages. This also enables developing some in-house design expertise to leverage for marketing purposes. This may be a very good solution for meat in the interim and will simplify the preparation to just emulsification and pod filling, both of which can be done in minutes compared to multiple hours for screening.

The limitation will be the design detail that can be achieved using a 2.0 mm instead of a 1.2 mm nozzle. For meat type products, it is considered that this level of detail is not necessary, and therefore not seen to impact any of the current designs available. As a first step, discussions with several of the 3D printer manufacturers could be held to assess the feasibility (Note that Foodini 3D printers use a wide range of nozzle sizes from 0.5 mm upwards).

A successful process was developed to produce 40 pods of 3D printing meat ink. The main challenge with the process developed is the time and effort required to screen oversized connective tissues and fat, noting that this step in the process is the most crucial.

It is recommended that consideration be given to the design prints required, as increasing nozzle size could be achieved, eliminating the screening step through clever drawing design. This would also give MLA in-house marketing skill to leverage in advancing 3D printing of meat.

The project has successfully completed the acquisition, trialling and evaluation of two 3D printers. A follow up training session was completed with key operatives at the MLA Sydney offices. Tutorial videos and operating procedures have been compiled for both the Createbot and ByFlow 3D printers, but training is still a requirement.

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1 Background

3D printing, first and still is used for parts manufacture of material goods from plastics or metal, is a form of additive manufacturing where a layer at a time is laid down to progressively build a product form/design. For both plastics and metal, it has enabled intricate and innovative designs to be manufactured at considerably lower cost.

This technology has progressed into food over the last five years and can be seen presenting food shapes with intricate detail, particularly with chocolates and sugar confections. While it has been applied to pasta, vegetables, meats and doughs the same level of detail is limited by both the multicomponent nature of these foods and the limited ability to immediately fix/set the extrusion. Hence the designs tend to rely on the viscous support of the food material which can vary widely. However, applications within food catering and professionals are growing and machines are being designed to target these markets like the Foodini, ByFlow, 3D Systems, Bocusini and Procusini (refer to V.RMH.0034 Review of 3D printing and potential red meat applications). It is proposed by Natural Machines COO that in 5 to 10 years these machines will start to be used in homes as they are developed to cook not only print the food, similar to microwaves.

A previous MLA project has reviewed 3D printing and potential red meat applications (R.VMH.0034). The outcomes were a research paper on 3D printing and red meat applications were presented at the BIT's 2nd World Congress of 3D Printing, Qingdao China Trade Show. The current project is an extension of previous work and proposes to develop 3D printing samples and seek feedback at industry events. Operating protocols for various 3D printers will be developed along with video footage, which will be used to train MLA operatives in running 3D printing demonstrations.

The purpose of the project is to develop 3D printed meat samples for demonstration at industry events. The project will also develop operating procedures and deliver training sessions to MLA operatives to operate various 3D printers units.

2 Project objectives

The overall objective of the project is to develop 3D printed meat samples for demonstration at industry events. The project will also develop operating procedures and deliver training sessions to MLA operatives to operate various 3D printer units.

The specific objectives were:

- Prepare meat pods, freeze (estimate making 40 pods) and transfer to MLA offices North Sydney for frozen storage.
- Produce video footage in how to set up, change settings and run 3D Printers and prepare meat pods and pack up machine ready to freight.
- Prepare small report (in MLA final report template) listing operating procedures and evaluation of Foodini and Createbot units (currently stored at MLA North Sydney) and ByFlow unit (currently stored at Monash).

- Deliver training sessions to MLA staff (assume this will be done in Nth Syd office (min 2-3hr Staged approach per session) in Melbourne and Sydney (in two sessions).
- Purchase two new "patterns" each (ie four in total) for the two MLA own units and commission.
- Seek industry feedback and review supporting value propositions for inclusion of 3D printing meat from previous research to build next stage adoption plans.

The outcome was to submit an industry report demonstrating the findings of the project.

3 Methodology

3.1 Staged approach

A staged approach was applied to undertake the project. Specifically:

Stage 1: Develop samples for industry demonstrations.

- Operate 3D printers & prepare meat pods and pack up machine ready to freight
- Prepare meat pods, freeze (estimate making 40 pods) and transfer to MLA offices North Sydney for frozen storage
- Arrange freight to transfer Monash 3D printer units (estimate this to be return courier from Monash to Alice Springs for MLA AGM and Monash to MLA Nth Syd head office at least twice)

Stage 2: Develop operating protocols including videos and conduct training of MLA operatives.

- Develop operating protocols for the various 3D printers including Foodini, Createbot units (currently stored at MLA North Sydney) and the ByFlow unit.
- Produce video footage in how to set up, change settings
- Project schedule signed off by the project group. A preliminary report submitted to MLA including
- Develop project schedule for production of 3D printing samples and demonstrations

Stage 3 – Reporting and industry feedback.

Seek industry feedback and review supporting value propositions for inclusion of 3D printing meat from previous research to build next stage adoption plans. An industry report submitted to MLA including:

- Operating protocols of the various units (Foodini, Createbot and ByFlow)
- video footage in how to set up, change settings
- Feedback from industry & training sessions
- Recommendations of next steps

3.2 Procedure

To ensure success of demonstrations, both sufficient and functional supply of 'meat ink' needed to be prepared, along with concise and accurate operational instructions. This was achieved by hiring a food approved laboratory at Monash University for 4 days, providing sufficient time to prepare and trial 'meat ink' pods while recording videos of preparation and key procedural steps. Although the videos were elementary with minimal production support, they were completed as an adjunct to written operating procedures, so effective demonstrations could be achieved with minimal technical awareness if necessary.

To prepare 40 plus meat pods a different process was adopted from initial development work done with the 3D printer manufacturer Byflow (work completed for the 3D printing conference at Monash), in that the scale needed to be increased. This was achieved using; a lower 'gristle' content meat (butchers 'premium mince'), a larger food processor (a 2kW Breville kitchen Pro), a larger non-plastic screen (a stainless steel Treton 400m fine-mesh screen), and a manual sausage stuffer for filling pods with the 'meat ink'.

The pods were sealed (with pod 'plunger' and foil over the tip), frozen and tested for effective printing after thawing (overnight in a fridge), then packaged in vacuum-sealed bags and shipped to requested locations. A 3D printer with a memory stick containing the training videos and operating instructions was also dispatched separately to a specified location.

4 Results

4.1 Meat ink preparation

A brief flow chart of the meat ink preparation process is shown in Figure 1. A more detailed operating procedure is included in Appendix 1, and 6 short video tutorials were provided with this report.

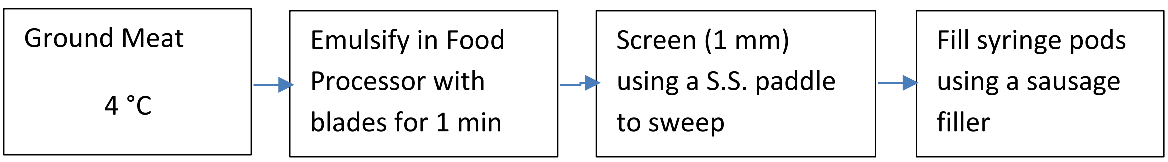

Figure 1. Meat ink preparation process flow

4.1.1 Meat source

Initial trial work utilised meat trim from a range of cuts, while this is fine for small scale preparations (1 or 2 pods) it was found that premium butchers mince was a better starting meat source for large volumes, as there was less gristle (elastin) collagen and fat. These required much more cutting and emulsification and results in more heating which needs to be avoided (spoilage) as the meat ink preparation takes some time.

4.1.2 Emulsification

While stick mixers and Thermomix type units can size reduce and mix well, they both result in too much heat generation. The Thermomix units were also very poor at emulsifying. The standard food processors were found to be best utilising sharp blades, large volumes (processing unit at least half full) and minimum time (1 to 2 minutes).

It is proposed that should future work require larger volumes (as in multiple printers or continuous printing as the Foodini may potentially do) it may be more efficient to use a commercial emulsifier and then screen.

4.1.3 Screening

The screening process step is the most arduous and critical, it requires significant time and a well-practiced technique. Regardless of the time spent in the emulsification step, both fat and connective tissue can be found that will block the nozzles on both the Createbot (using white nozzle) and byFlow (using olive green nozzle) 3D printers and hence must be screened.

The likelihood of a good 3D printing demonstration relies heavily on the success of the screening. Hence the smaller the aperture (mesh size) of the screen, the better the 'meat ink' will perform. A screen aperture of 1mm (Trenton 400 mm fine mesh screen) was found the largest acceptable for these two printers using the nozzles specified above.

It should be noted here that each drawing has been 'sliced' with the nozzle specified, so changing nozzles for a particular design will require re-slicing the original drawing (which is usually in STL file format). If you have this file, this can be done with free on-line available slicing software like Slic3r or Ultimaker Cura 3.0.

4.1.4 Filling syringes (pods)

The filling of the pods requires minimal air entrapped as this impacts the accuracy of the 3 D printing (air being compressible). This can be achieved using a teaspoon loading each spoon full into the pod and pushing it a little way up the tube with the back of the teaspoon. This process while effective is very slow, so should be used if a few pods only need filling.

The preferred method is to use a manual sausage filler or any small pumping system and attaching a small plastic hose to feed into the pod. When the 'meat ink' is feed to the end of the hose, the hose is inserted all the way into the pod and as pumping is started, it is withdrawn slowly until the pod is full, ensuring no air is entrapped. The success of this procedure is improved when the pod is held at a 45 degrees upward angle.

Once the pod is fill, its plunger is inserted to seal it and a small piece of foil or cling wrap used to cover the pod nozzle end. Each pod or several of them can be vacuum packed and frozen if not needed immediately. Alternatively, they can remain chilled (2 to 4°C) if to be used in the next day.

If frozen, thawing overnight in a refrigerator is the best method to prepare for use, alternatively the vacuum pack could be thawed in water. It pays to check if pods have been thawed effectively by extruding some meat ink out using your finger to push the plunger and checking if ice is still present.

4.1.5 Transporting 3D printers

3D printers are delicate machines and require professional packing for transport and fragile handling. There are any number of transport couriers familiar with these requirements and if given sufficient time are quite economical, this project used Pack & Send.

Each of the 3D printers are quite different, the most travel friendly is the byFlow and this may be taken on a plane as carry-on luggage. Evaluation of transport is covered more in the final report.

4.2 3D Printer evaluation

Each of the 3D printers for evaluation are similar in that they all operate as food paste printers. However, each is quite different in design and target potentially different markets. This assessment focuses on the MLA application, which is for red meat 3D printing demonstration purposes, and all those aspects, which are key to generating a successful outcome.

Following an initial exploration of the first two printers, (ByFlow and Createbot) a list of criteria was developed to best differentiate these for the purposes of red meat 3D printing demonstration. These criteria are detailed in Table 1, which presents a comparison of all three 3D printers.

One of the initial barriers new adopters of 3D printing have is being able to take a design and turn it in to a 3D printed object. There are free software providers that make their software available for this conversion, two of these are Slic3r and Ultimaker Cura 3.0. These two brands of 'slicing software' can work with a number of source drawing files and 'slice' them into 'gcode'. However it is very important that it is understood that the gcode generated will work for a given material at a given temperature with a given nozzle size. This is because these aspects affect the flow rate of material and the whole 3 D printing process hangs on getting this just right. So when converting a design into an 3 D printed object it can take a few iterations to get the right balance.

It is recommended here that initially while becoming familiar, the designs provided be used, and as a user becomes familiar with the process then experimenting with different nozzles and temperatures be explored. Then using in-house drawings converted to gcode will be much more successful.

Additional to this, while the demonstrations will most likely be run by the chef, it is recommended that additional technical expertise be developed in-house to support the chefs as there is quite a bit to a finished product that requires an investment in time and knowhow, which the chef will only need an awareness of to successfully run demonstrations. Simply put, it is perhaps more efficient to have the chef demonstrating than sorting out flow dynamic and software issues.

Table 1. A list of criteria was developed to best differentiate these for the purposes of red meat 3D printing demonstration

Comparison Criteria	Createbot	ByFlow	Foodini
Primary target market	Plastics printing software adapted to paste	Both paste and plastic printing	Paste printing
Information support	Poor, most in Chinese, what isn't is for plastics, has on-line software update	Excellent, including quick start menu	?
Equipment presentation	Solid, heavy, engineering	Sleek, light and clean	Functional?
Operating interface	Small, on the side, colour, hierarchical menu	Small, centre front, one colour, flat menu	?
Customer presentation	Difficult to see whats happening	Easily visible	?
Printer functionality	Extremely viscosity sensitive, does not like meat ink. Works very well with provided 'vege' inks	Adaptable, good with meat ink, heated bed aids functionality, great with "vege' inks	?
Loading files	Requires an App and binding of an internet link, files can be accessed directly by memory stick once done	Requires internet link, file loaded up to ByFlow and back to printer.	?
Annoying aspects	Need to 'Z Home' every time the print head returns to home.	Often loses Z setting and nozzle gets bent requiring a reboot	?
Additional aspects	Very large on-line library of designs, unfortunately all for plastics	As a printer owner access is granted for a selection of excellent designs in gcode on-line – good for meat	?

So far the preferred 3D printer for meat would be the ByFlow, but the Foodini appears to have a lot of options additional to the ByFlow, so assessment of this will be worthwhile.

4.3 3D printing operating procedures

Generally speaking, both the Createbot and Byflow 3D printers have effective operating procedures. However, the Createbot using a hierarchical menu makes it challenging to make adjustment on the run, as it is easy to forget where you are with some of the screen pages looking similar.

Operating procedures for the ByFlow 3D printers is included in the Appendix (see Figures 2 & 3).

5 Discussion

The project has successfully completed the acquisition, trialling and evaluation of two 3D printers. A follow up training session was completed with key operatives at the MLA Sydney offices.

It is noted that food 3D printing appears to be primarily paste printing with most of this relying on the viscous nature of the food to hold shape prior to further cooking or use, meat ink being the same. The only products that currently employ a 'setting/fixing phase' is chocolate and sugar, which both employ crystallisation (chocolate with fat).

It is highly likely that meat could be 'fixed' as discussed in V.RMH.0034, the Queensland University report (Godoi and Sangeeta) using its natural constituents. An alternative maybe to add a thickening agent (around 0.2% w/w) or using a blended gum like alginate and lightly misting a calcium chloride solution over the printed material, fixing it within a few seconds. These options do not eliminate the issue of needing to screen the material, which is the current substantial bottleneck in preparing 3 D printed meat ink.

The solution may be to print with larger nozzles and being smart about the designs utilised. Benefits of doing this are that it substantially reduces the 3 D printing time while reducing blockages. This also enables developing some in-house design expertise to leverage for marketing purposes. This may be a very good solution for meat in the interim and will simplify the preparation to just emulsification and pod filling, both of which can be done in minutes compared to multiple hours for screening.

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6 Conclusions

A successful process was developed to produce 40 pods of 3D printing meat ink. The main challenge with the process developed is the time and effort required to screen oversized connective tissues and fat, noting that this step in the process is the most crucial.

It is recommended that consideration be given to the design prints required, as increasing nozzle size could be achieved, eliminating the screening step through clever drawing design. This would also give MLA in-house marketing skill to leverage in advancing 3D printing of meat.

To date the ByFlow printer appears the best for meat demonstrations being flexible, smart, and simple to operate.

Tutorial videos and operating procedures have been compiled for both the Createbot and ByFlow 3D printers, but training is still a requirement.

7 Bibliography

Godoi, Fernanda C. and Sangeeta Prakash and Bhesh Bhandari. *V.RMH.0034 Review of 3D printing and potential red meat applications*. Sydney: Meat and Livestock Australia Limited, 2015.

8 Appendix – Supporting documents

8.1 Normal text Meat ink operating procedure

This is a food processing operation and should be carried out following good manufacturing practice

Ground Meat 4 °C →	Emulsify in Food Processor with blades for 1 min →	Screen (1 mm) using a S.S. paddle to sweep →	Fill syringe pods using a sausage filler, close off and vacuum pack

As the meat ink process takes time, it pays to keep the meat supply refrigerated while processing in 'food processor batch' lots.	A food processor with multiple blades, like the Breville 2kW Pro, is preferred. Fill the processor at least half full and monitor meat temperature. Keep meat below 10 °C and rechill if necessary. Processing time should be less than 3 minutes	Ensure the meat is 4°C, as screening takes some time. Screen in 300 g lots to minimise meat warming and refrigerate as soon as the meat ink is collected. After each 300 g, clean the screen using pressured water to remove the fouled connective tissue	Using a manual sausage filler, fill the pods by feeding meat ink in on a 45 ° upward angle. This allows air to expel and enables very rapid filling. Insert pod plunger and a piece of foil over the nozzle end, if freezing allow an extra 10% space for expansion. It is often beneficial to vacuum pack a number of pods together

See additional video tutorials;
1. Emulsifying
2. Intro to screening
3. Screening
4. Screening 2
5 Screening 3
6. Loading syringes (pods)

8.2 3D printing operating procedures

The two Adobe PDF below are the detail operating procedures (see Figures 2 & 3). A quick start menu. These two documents should be reviewed with the video tutorial for a better understanding of operating.

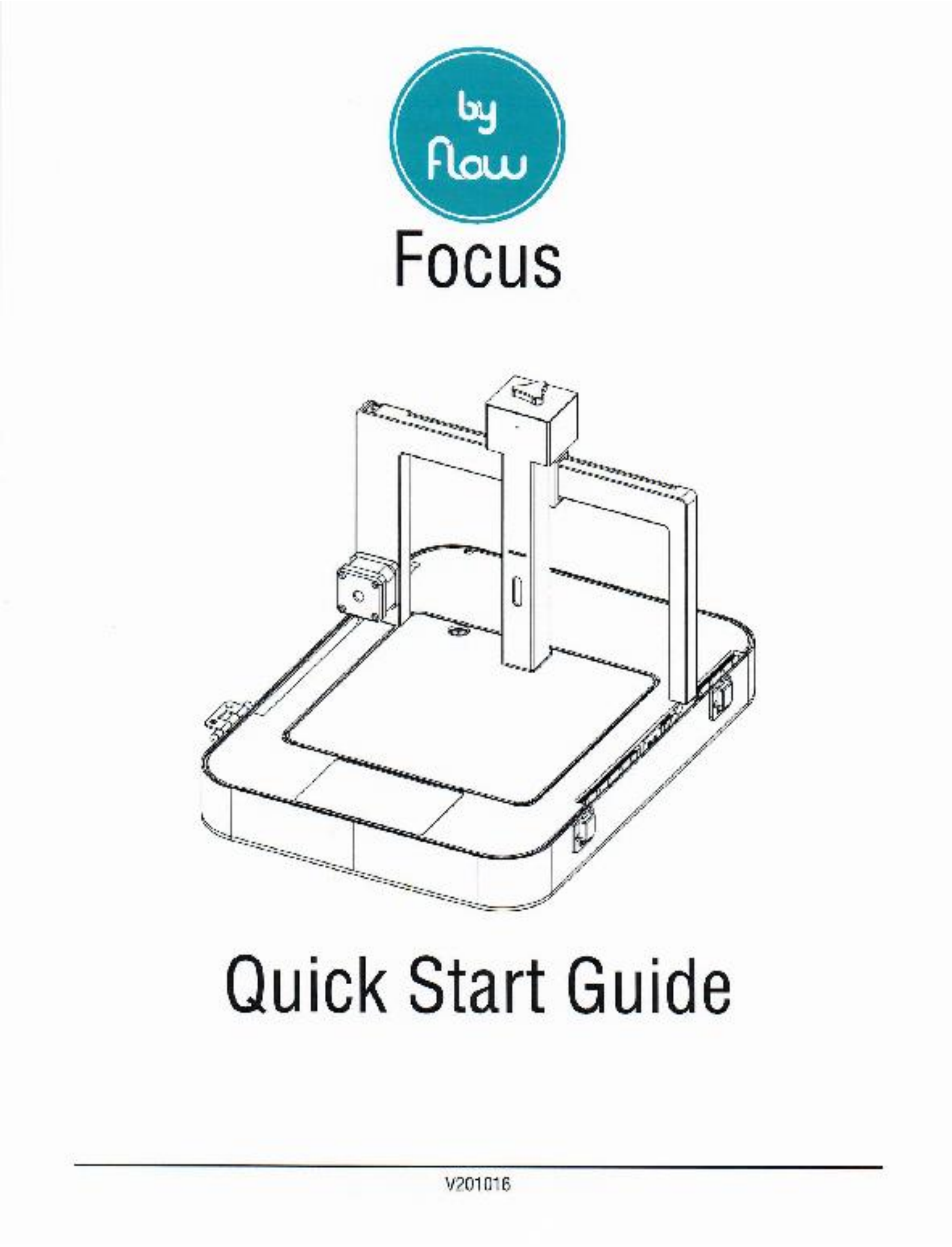

Figure 2: Quick start operating procedure for the ByFlow 3D printing unit.

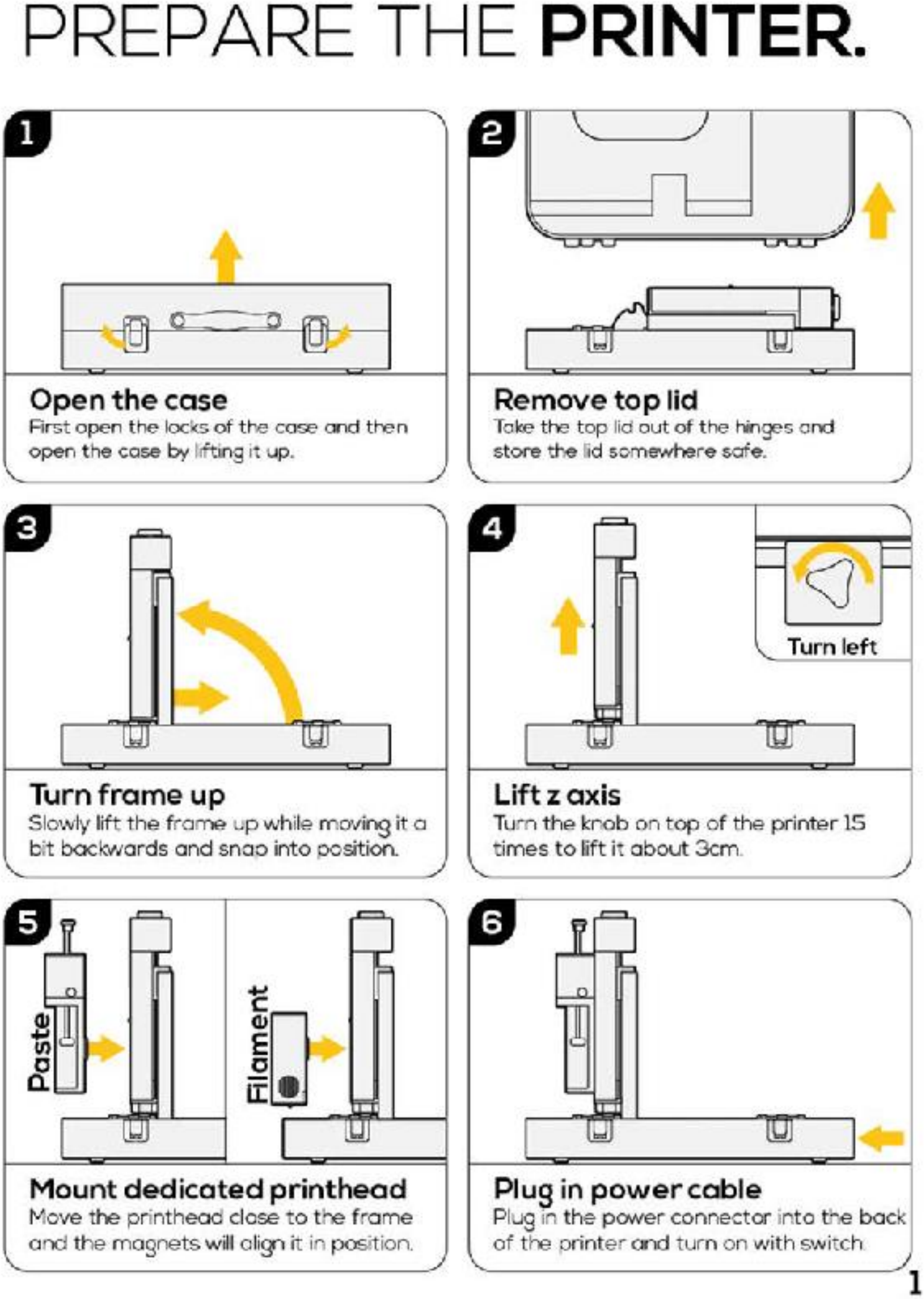

Figure 3: Detailed operating procedures for the ByFlow 3D printing unit.