Investigations into

MEDICAL WASTE

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Executive Summary

The waste generated by the medical industry each day is often overlooked and misunderstood as "just how it is". Informed by multi-method research, this paper presents findings based on grounded theory methodology. By utilising industry software, ATLAS.ti, to deconstruct and analyse interview transcriptions and cultural probe data, we can picture a story of failure in processes leading to an excess of unnecessary waste. This study includes participants intimate with hospital and private practices, investigating their relationship with medical waste and offers insights into an underserved section of medicine.

A design solution is justified at the end of this report that solves many of the issues that arose during the research phase.

Acknowledgements

In the spirit of reconciliation, I would like to acknowledge the Traditional Custodians of the country throughout Australia and their connections to land, sea and community. We pay our respect to their Elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples today.

I also want to acknowledge those who have supported me in reaching this milestone with a special thanks to Dr Shayne Beaver and Andrew Scott for offering thorough feedback and support at every stage throughout the year. I would also like to show my appreciation for my partner Myf and my housemates Gemma, Morgan and Imogen for putting up with my late nights. I also want to show my gratitude to the interviewees and the general practice here in Brisbane, Australia, for allowing me to do my interviews and cultural probe.v

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INTRODUCTION

It is ironic that as we create a healthcare system to continually better the health of its population, we also have created a society with which the same system now generates 8 billion tonnes of waste a year, rivalling the food industry (Ordway et al., 2020; Wyssusek et al., 2020). This wasteful machine results from years of stigma and legislative reform stemming from the AIDS epidemic of the 80s. Today, the attitudes within medical practices highly reward the excessive packaging and over-discarding of medical devices. Single-use medical devices have become a favoured instrument by many practices, big and small, due partly to their short-term economic savings and thought to be "less hassle" by medical staff (McGain, 2010). Globalisation has developed a system that affords a cheap and affordable single-use class of products in countries with high labour costs, ruling out the processes required to maintain reusable alternatives. Efforts internationally have risen across faculties of medicine to reduce, reuse and recycle their waste streams in response to growing concerns of climate change has presented to the world. Research initiatives within hospital systems have revealed many causes for concern with existing practices medicine has come to accept. Key points of concern include the failure to segregate waste by type and hazardous status and the excessive packaging and liability pressure resulting in over disposal. It has become commonplace for medical staff to joke about "being dressed in oil" due to the excessive use of single-use products typically derived from petrochemicals (Terzon, 2021). So what can be done about this wasteful culture?

Promising initiatives within Australian hospitals have shown us that there are simple practices that can afford impactful results. Dr Forbes McGain from the Western Hospital in Victoria has led or inspired much of the research the following literature review discusses (Terzon, 2021). McCain's efforts have afforded initiatives within his hospital to replace single-use anesthetic equipment with reusable alternatives in operating rooms, saving the hospital roughly $30,000 annually. Dr Wyssusek et al. (2020) of the Royal Brisbane and Women's Hospital (RBWH) captured all of their PET waste generated by their operating theatres, saving nearly two tonnes of waste destined for the landfill diverted to recycling facilities for further processing. Reducing the financial strain on the hospital and also the environmental impact.

While these initiatives have shown promising results, much of the existing literature discussed has research sources from large hospital institutions. This represents a bias in the data and does not represent the whole picture, with much of the population visiting general practices and dental clinics far more often than the hospital. This study needs to research this missed industry and develop opportunities to improve the well-being of the medical practitioners and patients underserved by contemporary literature (Australian Bureau of Statistics, 2021). Figure 1 defines the structure of this paper.

Literature Review

Exploration
Discovery
Methodology

Primary Research

Interivews + Cultural Probe.
Analysis & Findings.

Design Proposal

Discussion
Opportunities
Criteria

Figure 1. Document Outline

LITERATURE REVIEW

WASTE IN THE MEDICAL INDUSTRY

Over the past several decades, the medical industry has transitioned from the practice of cleaning and sterilising items for reuse; to the mass consumption of single-use items disposed of after each use (Kagoma et al., 2012; Merritt et al., 2000). This overhaul was partly due to the HIV/AIDS epidemic of the 1980s, and the fear of blood-borne diseases introduced increased regulation across the industry, which resulted in the increased consumption of single-use products (Laustsen, 2007). Today, the production and disposal of medical goods contribute seven billion tonnes of medical waste to land-fills, making the industry the second largest contributor to land-fill behind the food industry in the United States (Ordway et al., 2020; Wyssusek et al., 2020). However, research suggests that only 2% of hospital waste was recycled in many western countries (McGain, 2010). The frequency of waste produced exacerbates this; one Australian report finds that they make 5kg of waste per patient daily (McGain, 2010).

"A healthy ecosystem requires a healthy environment, and anything that alters ecosystem health also may alter the health of its inhabitants."

- Dr Gary Laustsen (2007)

Single-use medical devices afford much of the waste a medical practice disposes of (Duane et al., 2019). These single-use components include cotton drapes, theatre gowns, respiratory devices, bowls and even metalware devices such as scissors and containers (McGain, 2010). While reusable alternatives exist, many practitioners are reluctant to use them, citing cost as the main reason (Moultrie et al., 2015). A pay-per-use business model has become much more appealing and approachable for management where the costs and liability associated with cleaning reusable equipment may be difficult to monitor (Alfa, 2013; Moultrie et al., 2015). Liability concerns are often discussed in the literature, where many medical institutions are risk-averse to any opportunities that could afford contamination between patients. (Alfa, 2019; Goldberg et al., 1996; Moultrie et al., 2015). These two drivers, cost and liability, enable the consumeristic behaviours we find within many medical institutions. The effect is ironic when we consider the purpose of medicine and its Hippocratic oath in contrast to the environmental impact the industry has on the people it serves (Kagoma et al., 2012).

Sources

In 2010 the Victorian public hospital system produced the equivalent of 200,000 households worth of waste, costing the network an estimated 10 million dollars (AUD) annually to discard (McGain, 2010). However, medical waste is regarded differently than regular household waste, where much of the waste is considered bio-hazardous. This difference in distinction increases the cost of medical waste tenfold, where it costs roughly $1/kg to dispose of within the Australian market (McGain, 2010). Research inside the hospital reveals that the largest source of medical waste originates from the operating rooms, where an estimated 33% of an entire hospital's waste is generated from these relatively small zones (Goldberg et al., 1996; Kagoma et al., 2012). Furthermore, studies suggest that up to 80% of the waste generated by the operating room has already occurred before the patient arrives. Therefore, much of the waste from the OR is clean, uncontaminated and easily recyclable (Wyssusek et al., 2020).

However, of all the waste created, it is often discussed that as little as 10% of that disposed of material is hazardous to humans, with much of the waste taking the form of packaging and paper (Babanyara et al., 2013; Laustsen, 2007; McGain, 2010). Literature, however, tells us that there is a constant challenge in keeping these two branches of waste separated inside the hospital environment (Kagoma et al., 2012, p. 1907)

Figure 2. Types of waste categorised by risk (Babanyara et al., 2013; Laustsen, 2007; McGain, 2010)

The current world pandemic, COVID-19, has significantly increased this medical waste generation. Literature indicates that medical waste disposal has risen significantly across the globe. One Sydney landfill reported that medical waste disposal has increased by 35%, with some Chinese provinces indicating that they have seen a 600% increase in medical waste (Andeobu et al., 2022). Suggesting that the contemporary medical waste problem we are discovering may continue to rise without proper interventions. Media coverage has only improved on how topics regarding medicine are discussed in a public forum, with more eyes being directed to the existing medical waste problem (Terzon, 2021).

Risks & Hazards

An estimated two million healthcare workers globally are exposed to percutaneous injuries from infected sharps yearly (Prüss-Üstün et al., 2005). A majority of which resulted from handling found during the disposal stage where there may have been improper packaging of waste (Blenkharn & Odd, 2008; Chartier et al., 2014). The most significant hazards found with medical waste typically come from blood-borne diseases such as Hepatitis B and C and HIV in rare cases. These perceived risks further promote the use of single-use devices as there is a reluctance found from waste-handling personnel with the practice of recycling and reusing (McGain, 2010). Inappropriate handling of waste has also afforded increased regulation in the industry, which increased the reliance on disposable medical devices (Laustsen, 2007).

Economics & Environment

With medical waste costing tenfold to dispose of compared to your typical waste, single-use devices' financial burden on the industry is undeniable (McGain, 2010). By replacing the anaesthetic equipment in one Australian hospital with reusable devices, a group of researchers were able to reduce the hospital costs by roughly $30,000 per year; however, this posed environmental implications. Measured CO_2 emissions increased by almost 10% from the change. This impact was to be the result of the power source mix found within Australia. Similar studies in the UK with a greater degree of sustainable energy suggested reductions in CO_2 emissions were present. The consumption of water was also found to be higher with the increased need to process individual devices (Goldberg et al., 1996; McGain et al., 2017). Suggesting that a more considerable institutional change and further technological development need to increase the efficiencies of reprocessing techniques and more sustainable power sources.

The environmental and societal impact in developing countries is much more severe due to a less sophisticated waste treatment infrastructure. Concerns regarding poor medical waste management include increased environmental pollution of land and water sources and the proliferation of disease-carrying insects and rodents (Babanyara et al., 2013). Literature also displays concern for the ineffective capture of harmful gases such as Nitrous Oxide ($N20$) used in anaesthetics, which is considered a powerful greenhouse gas, 280 times more potent than CO_2 (Duane et al., 2019; Ordway et al., 2020). Within British dental practices, it is estimated that, on average, 163 litres of $N20$ is consumed per patient, which is equal to roughly 90kg of CO_2 (Duane et al., 2019). Technology exists to capture and neutralise the gas; however, it is typically reserved for larger institutions such as hospitals rather than local dental clinics. In conjunction with the estimated water consumption of 33 thousand litres per surgery each year at the same dental clinics, the environmental impact the medical industry across sectors has on the community is evident.

One New Zealand based research team surveyed all dental practices in the country. It found that roughly a quarter of responding dental clinics

disposed of all their waste through household waste collection methods.

Evidence suggested that many of these clinics were typically located in remote areas indicating an infrastructure failure. Reasons cited included cost as a factor and the perception that the waste was being discarded in domestic waste regardless, so the need to save costs on complex disposal procedures was favoured (Treasure & Treasure, 1997).

Incineration

The primary method of disposing hazardous and infectious medical waste is through incinerators in developed countries. The residual waste ash can be disposed of in council landfill facilities (Windfeld & Brooks, 2015). The benefits of this process ensure sterilisation of waste resulting in unrecognisable ash, reducing transport and landfill impacts and costs (Lee & Huffman, 1996). However, environmental health complications exist as a result of the incineration process. The incineration of some plastics and metals can release pollutants, including dioxins and furans, considered human carcinogens (Babanyara et al., 2013). Opportunities exist to reduce the impact these air-borne pollutants have on the public's health. However, they remain prohibitively expensive even for many hospitals to commission (Windfeld & Brooks, 2015). Autoclaving in literature is considered more environmentally friendly when compared to incineration as it does not release its byproduct into the environment. However, it does offer drawbacks because the process inherently does not affect the appearance of the waste. Typically many institutions will autoclave and then incinerate their infectious waste as many communities respond with resistance to non-incinerated medical waste in their landfills (Windfeld & Brooks, 2015).

Research Gap

Most interestingly, the literature fails to identify the waste impact of localised medical practices' on the environment and community they reside within. Most of the research has solely focused on the hospital institution as the context of their research. This could be attributed to too much of the researcher's funding being sourced from government entities whose interests lie in the hospital. With what little research does exist regarding private medical practices, it is typically limited to the dental practice. However, the need to develop a greater picture of the topic of discussion is perhaps more important than the hospital institution itself. The Australian Bureau of Statistics (2021) finds that within Australia, 82.4% of survey respondents (n=28,386) visited a general practice, 47.9% saw a dental professional and only 12.5% were admitted to a hospital. Indicating that the average citizen has more contact with a general practice or dental professional than the hospital system.

However, much of the literature does provide insight into existing practices large institutions do to reduce, reuse, and recycle their waste. The following discussion explores those techniques employed by hospitals, discovering what is effective and highlighting the pain points many medical professionals have when disposing of their waste.

REDUCE, REUSE, RECYCLE

The three R's: Reduce, Reuse, and Recycle, have become the mantra of many environmentally focused movements, leaking their way into popular culture and becoming a commonplace activity in many residential settings (Abdul-Rahman, 2014). Sorted in order of importance, the three R's define the steps someone can take to reduce their environmental impact. First, reduce your impact by not purchasing that thing in the first place. Second, reuse what is acquired for as long as possible to reduce the environmental footprint—finally, recycling as a method to give new life to what is unusable.

Examples of this mantra can be observed in the community in many forms. Charity shops offer the opportunity to reuse what was once loved and provide new life, a form of fashion sustainability (Borusiak & Kucharska, 2019). Many local councils offer their residents bins and guidelines that allow the population to recycle a portion of their waste (Brisbane City Council, 2022). Reduce is often employed when considering packaging alternatives and bans on plastic bags to incentivise reusable options (Abdul-Rahman, 2014; Queensland Government, 2018). However, many of the efforts described apply only to the individual, and many commercial entities have fewer incentives to abide. We have already discussed the current medical industry practices, where the favourability of single-use components has taken up much of the industry's waste makeup. McGain (2010) finds that 93% of surgical waste could be adverted by recovering linen, paper, and recyclable plastics. One concerning fact is that up to 80% of solid waste produced from a single surgery will already be generated before the patient arrives in the room (Kagoma et al., 2012). Indicating where most of the issues present themselves, within the excessive packaging that many medical devices come in (Kagoma et al., 2012).

Existing Practices

Reprocessing

Existing practices employed in the hospital environment most commonly will involve using an automated high-pressure steam sterilisation machine (autoclave) to reprocess purpose-built medical devices (Tietjen et al., 2003). The autoclave is considered the gold standard, offering an effective and proven sterilisation method (Alfa et al., 2010). However, the costs of such machines may be prohibitive for some clinics, ranging from £8,000 (AUD 14k) to as high as £58,750 (AUD 103k) (Priorclave, n.d.). The training and infrastructure around the autoclave are also essential, limiting the range of applications for practical usage. For example, one study highlights that surgical-site infections are ten times more likely in developing countries than in US or European hospitals (Tao, 2012).

Figure 3. Mocom B Classic Autoclave Machine (Henry Schein, n.d.)

The global market means the manufacturing of single-use devices is preferred and often easier to justify economically as labour abroad is typically cheaper than using relatively expensive labour costs reprocessing requires in developed countries (McGain, 2010). This finding is further clarified at the Western Health Hospital in Melbourne, where McGain (2015) finds that the labour costs to reprocess a reusable metalware device are five times the price of its single-use counterpart in their hospital. However, analysis of the two variants of the same medical device reveals that besides the mechanical finish, they are both comprised of the exact essential details, down to the material makeup of each metalware device (McGain, 2015).

Chemical reprocessing alternatives also exist to sterilise; however, they are typically considered not as effective as the autoclave model (Chartier et al., 2014). The benefits of chemical sterilisation offer opportunities for reprocessing where electricity, labour or water quality may be an issue. However, the chemical process requires ultrasonic cleaning for the highest standard of sterilisation by chemical reprocessing. In addition, research suggests that the device to be reprocessed must not be left to dry before the sterilisation process (Merritt et al., 2000).

Single-Use Medical Device Reprocessing

The proliferation of single-use medical devices (SUMD) inside the medical structure is undeniable. Most manufacturers have warned about the reuse of SUMD, as the risk of infection or breakdown is high if proper sterilisation cannot be guaranteed (Jacobs & Akpinar, 2018). However, the market for reprocessing SUMDs has increased each year, with many hospitals reprocessing in-house and a thriving third-party industry forming in the early 2000s to meet demand. Cost is often cited as why this practice is usually performed (Jacobs & Akpinar, 2018; Kagoma et al., 2012; Popp et al., 2010). However, liability and safety concerns are discussed throughout the literature as arguments against the growing practice (Cohoon, 2002).

Opportunities

Separating Waste

Literature tells us that much of the infectious waste streams leaving hospitals comprise primarily of non-infectious material, making up 70 to 80 per cent of the volume. This is suggested to be the result of poor sorting practices within hospitals. Legislation exists in many developed counties defining what is medical waste. However, few instructions are employed telling us which objects can be considered infectious. This effect increases the volume of waste treated and incinerated by medical institutions (Windfeld & Brooks, 2015). Proper medical waste segregation from the operating room (OR) is often cited as potentially the most significant impact on costs and environmental footprint (Kagoma et al., 2012).

Innovation

The highest cost associated with the traditional autoclave system in developed countries is the labour involved in managing and processing a clinic's reusables and waste (McGain, 2015). Therefore, innovation in this space should automate more parts of the sterilisation process that require human attention.

Recycling

Several hospitals have published audits exclaiming the success of recycling programs employed in their waste streams. For example, the Royal Brisbane and Women's Hospital (RBWH) performed a month-long prospective audit of all 22 of their operating rooms (ORs) polyethylene terephthalate (PET) waste to help understand the total weight that is being discarded each day. The results afforded programs to better train staff and categorise waste within their hospital (Jones, 2020; Wyssusek et al., 2020).

Type of Plastic	Examples	Recyclable	Volume (%)
Polypropylene (PP)	Paper-like surgical instruments wraps Disposable forced air-warming blankets	Yes	21%
Polyethylene (PET)	Instrument wraps Intravenous (IV) fluid bags Warming blanket wraps	Yes	40%
Polyvinylchloride (PVC)	Oxygen masks, tubing IV fluid bags, giving sets Sucition Tubing	Yes	23%
Copolymers	Syringes IV Cannula Covers Yankauer suckers	No	10%
Polyurethane	Trays	No	6%

Figure 4. Plastics commonly found in the Operating Room (OR) in Australia. Adapted from Wyssusek et al. (2019)

SUMMARY

The exploration presented by the literature review has highlighted the importance and urgency of the medical waste problem we have not only in developed countries but also touched on those still developing. We have covered the sources of medical waste within the healthcare institution and discussed methods of processing that waste effectively. However, we should not ignore the irony in the contrasts between the purpose of the hospital and its environmental impact.

Research has proven that the mismanagement of medical waste will continue to harm the environment and its inhabitants. However, promising results from studies have demonstrated effective methods of dealing with the waste stream disposed of by hospitals. Undoubtedly our hospitals and clinics must continue to provide uncompromising high-quality care. However, the literature tells us that we may be able to become more environmentally aware without compromising either. Investigations into existing waste management practices offer insights into the limitations current practices afford. Cost and liability are often cited as barriers to what is discovered to be effective practices. Nevertheless, opportunities exist to improve upon the current processes within medical institutions.

Further research must be conducted to offer better solutions to a broader range of requirements. However, limitations still exist in the literature as much of the research being conducted is centred around the hospital system. With a vast majority of the population visiting a general practice and dental clinics rather than the hospital, it is clear that further research needs to be conducted to understand the problems associated with smaller practices' waste streams (Australian Bureau of Statistics, 2021).

RESEARCH PROPOSAL

This research aims to explore existing methods of medical waste management within the Australian medical industry. The study intends to afford design opportunities to facilitate the improvement of medical waste management practices by a product, system or service innovation. Solutions will focus on satisfying the needs of all the medical practitioners, clinic staff, patients and waste disposal providers, maintaining the high-quality healthcare we expect from the Australian public health system. This research seeks to solve issues within smaller, localised medical practices whose resources may be limited compared to larger hospital institutions.

Research Question

This research project investigates ***how health professionals can remain economically, socially and environmentally sustainable while reducing medical waste disposal in their practice?***

Sub Questions

Sub-questions derived from the literature reviews findings are posited to discover several medical waste management system paths.

1. What types of waste is being discarded?
2. What economic, social and environment priorities do health professionals have with their practice?
3. How do waste management processes differ between the hospital and medical practice?

Research Framework

The methodology has been selected based on what will offer the richest data to conclude opportunities. Figure 5 reveals the methodology structure, defining the relationship between two classes of medical professionals and cultural evidence. Data will be drawn from two asynchronous phases involving semi-structured interviews and a cultural probe into a Brisbane-based general practice. Discussions will include hospital and private practice perspectives across disciplines to develop brevity of information for thematic analysis. A cultural probe will also be conducted in conjunction with a Brisbane-based general practice to provide a quantitative form of research. These research methods have been favoured to compare the differences between the well-funded hospital system and private medical practices that may have alternate financial goals. As discussed in the literature review, it is crucial to investigate private medical practices' waste impact, as a gap in the research has been identified. It is also important to note that much of the literature on this topic is based on research that utilises quantitative discovery methods. The proposed methodology in this study uses qualitative forms of discovery opportunities to fill the gap in the research identified. The benefits offered by this distinction may be able to inform us to a higher degree about the existing waste management processes private medical practices have under a scope detailed in its analysis. Not only will empirical data be gathered, but more profound human experiences and behaviours will also be understood within these proposed methods of research offered.

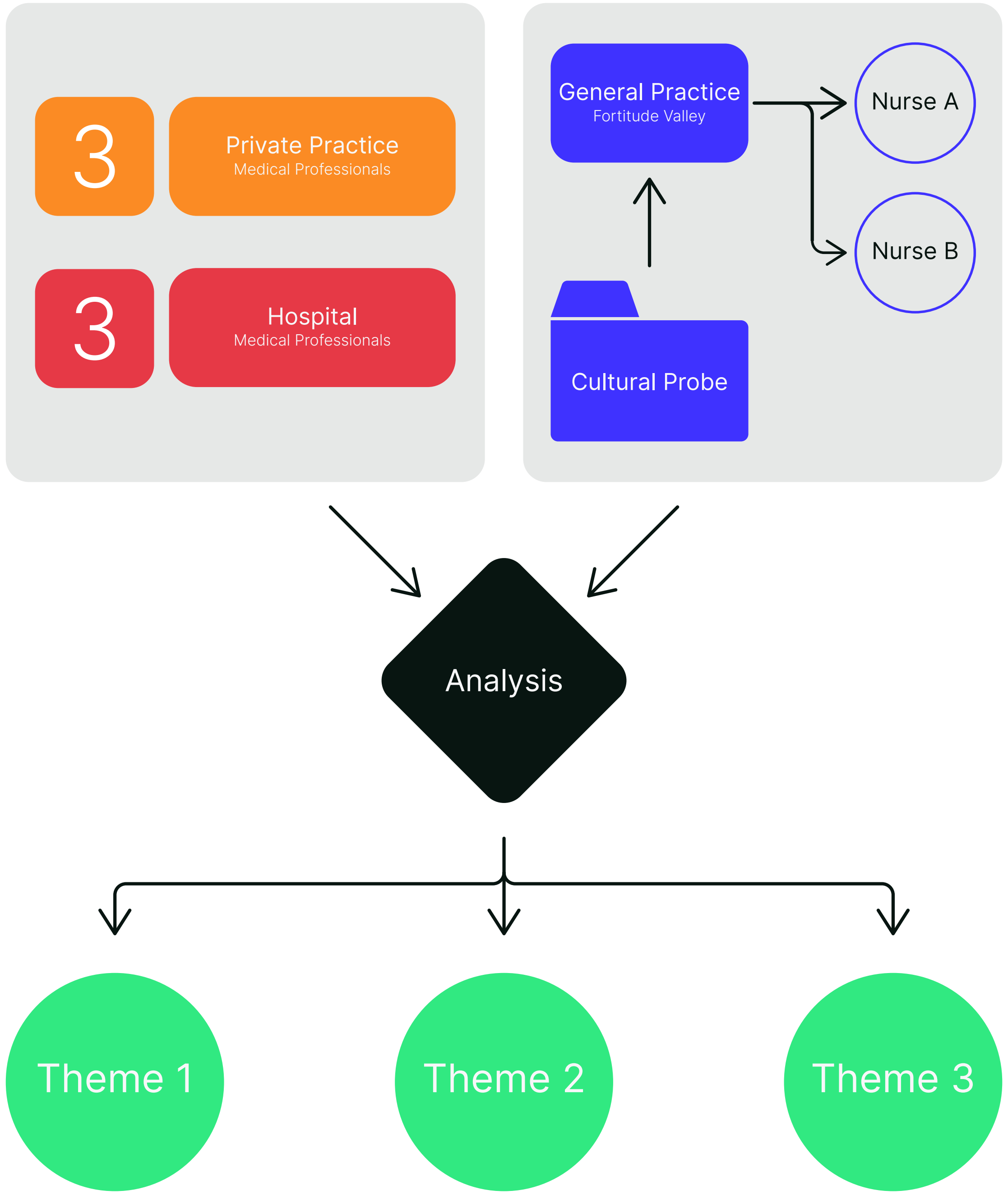


Figure 5. Research Methodology Map, Expanded.

METHODOLOGY

This study aims to develop a greater understanding of medical waste management processes found in private medical practices. Primary research will achieve this understanding by effectively using qualitative and quantitative methodologies to address the study's topic of discussion and objectives. To better understand existing waste management processes, we need to offer insights into what is being disposed of and comprehend the individuals' perceptions of waste. This knowledge will be essential to understanding the human issues found with existing practices.

Interviews

Interviews across both medical industry sectors will offer critical insights into how each perceives their daily waste management. The semi-structured interviews will include discussions with four nurses and doctors from public hospitals and three medical professionals in the private sector. This variety of experiences will enable a rich data collection process taking input from existing hospitals and private practices. In addition, this segmented approach will allow opportunities to bridge the divide between these two healthcare sectors. The interviews will be semi-structured and relaxed to open discussion, covering fundamental topics and allowing for a discovery process.

Data Collection

Interviews will be conducted across various mediums, both in person and over the phone. Both will be audio-recorded and transcribed to enable a coding process that we will use to discover the themes. With the use of semi-structured interviews as the type of research being conducted in phase 1, the flow and standardisation of each interview are essential. Each session will begin with a series of predefined questions that will help the interviewer and interviewee become familiar with each other to promote a further open discussion. The latter half of the session will involve a structure from wider-concept questions that both parties can work with for the interview duration. This approach offers a predictable structure across interviews that will aid in the thematic analysis process where codes can be made standard. Transcribing will be offered by Otter.ai to capture the discussions accurately, and specialist software ATLAS.ti will allow us to apply the thematic analysis methodology effectively.

The thematic analysis framework offers us a meaningful way to develop actionable insights. Analytical processes may be discerned from the deconstruction of transcripts into codes over a series of assessments, categories, and themes. Critical points of concern and opportunities will be recognisable by the relationships created between the codes, categories and themes (Hanington & Martin, 2012, p. 178).

Cultural Probe

Concurrently, a cultural probe into a private Brisbane medical practice will occur. Cultural probes offer methods to gather rich qualitative and quantitative information about people and their activities. By enabling the user to self-report, the cultural probe process allows them to collect information about activities with minimal influence on their actions. This is important to gather accurate data about waste management processes found within the practice. The kit and its material will attempt to engage with the user in a creative and varied style to promote deeper engagement by developing enthusiasm regarding its completion (Hanington & Martin, 2012). Maintaining this level of engagement is crucial to aid the development of meaningful responses by the user.

Data Collection

A cultural probe kit, pictured in figure 6, will be presented to medical practitioners within the chosen clinic where a self-reporting process may occur. Completing this kit will involve using several dated pages to be filled out each day of the week. Each form will instigate uniform quantitive capture methods by prompting the user to capture, with photography, the waste they discard throughout the day. This will be gathered by guiding the user to a brief survey to submit their photos online securely. This is then followed by qualitative prompts that will enable the practitioners to respond with personal thoughts and opinions in written form, with a response each day expected not to take longer than 5 mins. Novel usage of the kanban task management software, Padlet, will be used to capture images, videos and text over time that may be captured in analysis in real-time by the researchers. This synergy of technology and paper ensures a seamless experience while maintaining confidentiality agreements required for ethics. It is important to this study that bias be mitigated as much as possible when developing the questions and prompts for users to respond to. The survey material will reduce the bias found in its content by applying methods developed by Dr Bernard Choi and Dr Anita Pak (2004), describing common biases found in public health research. The data collected will be de-anonymised to offer privacy for the individual's waste practices. In addition, the kit will ensure the practitioner's data does not contain patient information to meet confidentially agreements the clinic has with its patients.

Example

Figure 6. Cultural Probe example sheets from kit.

ANALYSIS & FINDINGS

ANALYSIS

Six semi-structured interviews and a cultural probe with medical professionals from public hospitals and private medical practices were analysed to inform design solutions to improve medical waste practices. Figure 1 shows how interviews and cultural probes were deconstructed through a thematic analysis process and how the discovered opportunities were synthesised. Grounded Theory (GT) was employed to inform the structure of the analysis process, beginning with an initial coding stage to identify the social and psychological processes and actions discussed in the primary research gathered. GT is a flexible framework for discovering and constructing a data theory with a systematic comparative analysis (Chun Tie et al., 2019). This is especially useful in the context of this paper as there are often discrepancies found when comparing Hospital and private practice waste management practices. GT offers an effective method of comparison that will enable deep insights into the differences present.

After interviews were transcribed and formatted correctly with Otter.ai©, an initial coding stage followed, involving an open coding pass of a single interview that developed a basic structure completed using ATLAS.ti©. This structure was then applied and refined with further interview coding passes. Finally, once all six interviews had been coded, a second pass was applied to ensure an even application of codes was active across all interviews.

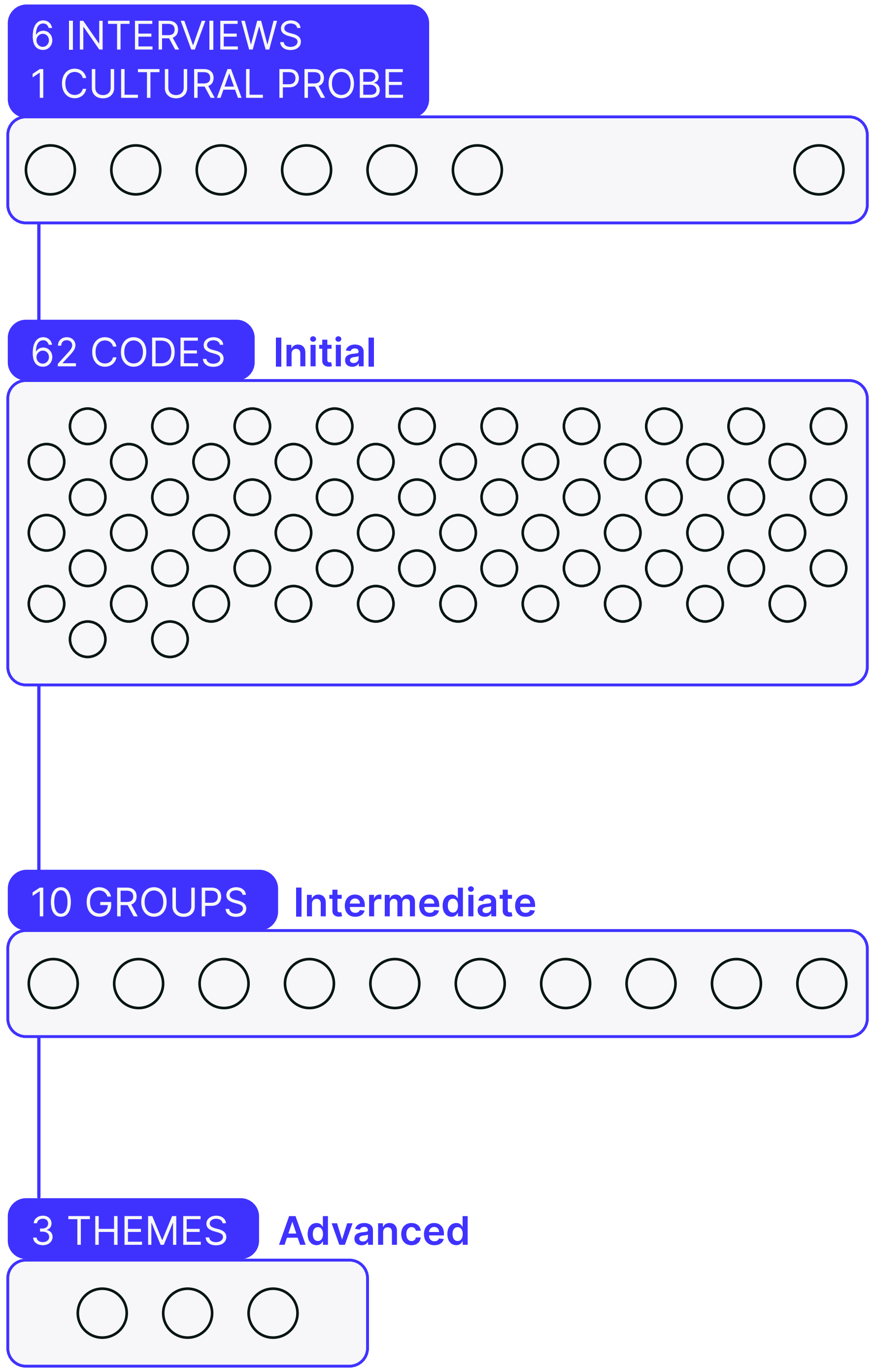


Figure 7. Grounded Theory Framework applied to interviews and cultural probe. Adapted from Chun Tie et al., 2019

FINDINGS

The research set out to understand existing medical waste practices and how they might differ between the hospital and private practice settings. Analysis of the collected data helped to discover themes that inform our understanding of the economic influences on waste (48.92%), the social implications of waste management (27.40%), and the environmental considerations by health professionals (23.68%). These themes, with collections of codes and groups, represent facets of the medical waste practices discovered in the analysis stage. The following section outlines critical opportunity areas through the analysis of interviews and cultural probes. Each area offers deep insights into important design considerations of a system or product to reduce medical waste within private practices.

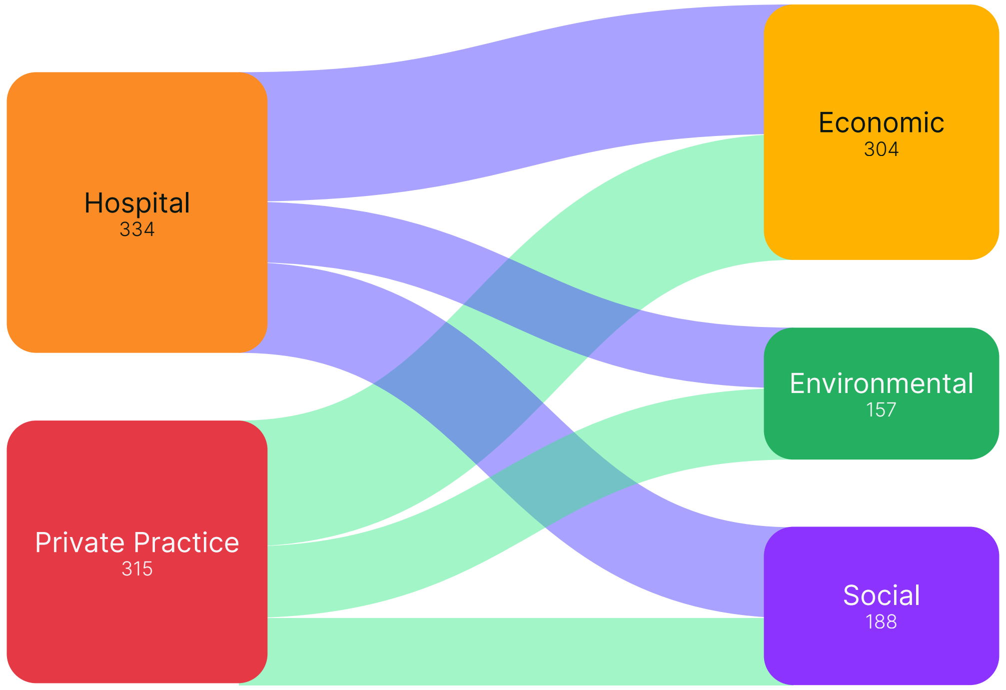


Figure 8. Breakdown of themes by Interviewee type.

Interviews

Hospital				3
1	**Danielle Beaven**	Registered Nurse	15 Years	QLD
2	**Dr Douglas Holt**	Intern Doctor	15 Weeks	QLD
3	**Martha Parsons**	Management	12 Years	NSW

Private Medical Practice				3
4	**Melissa Riddell**	Sonographer	2.5 Years	QLD
5	**Morgan Lemin**	Paramedic/Nurse	5 Years	QLD
6	**Dr Sagar Shah**	Dentist	6 Years	NSW

Cultural Probe

General Practice				2
1	**Participant 1**	Nurse		QLD
2	**Participant 2**	Nurse		QLD

Figure 9. Interviewes and Cultural Probe participants.

Economic influences on waste

It is evident that both medical professionals from hospitals and private practices unanimously place a greater emphasis on economic factors informing their practices over other identified themes (Figure 8). 'Cost' is discussed 27% of time as a leading influence on medical waste practices (Figure 11). Interestingly cost is found to be split evenly between both hospitals and private practices, identifying the common traits favoured by the medical industry as a whole.

"So I think the probably the cost of that actual packeted like single use packet may outweigh the actual cost of sterilisation, a piece of like a sterilisation machine, the staff to run it, you know, package it, get it back down."

- Danielle Beaven on Cost

However, stark comparisons can be made between both medical institutions. 'Time' is cited as a significant negative influence on waste production within the hospital environment. In contrast, none of the private practice participants discusses 'Time' as an impact on their practice (Figure 11). Being "time poor" is often emphasised when discussing time which also correlates with another finding under the social theme regarding being 'Busy', which is again solely discussed by hospital professionals.

"...sometimes these things fall by the wayside when you are just trying to get enough ICU beds up and running."

- Douglas Holt on Time

In contrast, private practice health professionals 27% of the time cited 'Sterilisation' and 'Standardisation' 20% of the time as the most prominent influencer on waste rather than mentioning time as a factor at all leading to more significant waste. This aligns with the private practice participants' experiences where the standardisations of medical devices in pre-packed kits or 'Procedure Packs' were often discussed as a cost-savings method as it keeps production and purchasing slim. Results from the cultural probe reinforce the finding where it is discovered that the general practice investigated uses single-use metalware devices (Figure 10). Further investigations into the devices reveal to us that they were typically one-sixth the cost of reusable alternatives before the labour required to sterilise equipment is accounted for.

"Everything's packed in one size. And so if you need, 10 centimetres of a bandage, but it's a meter long, then you're going to have to throw out the rest."

- Morgan Lemin on Standardisation

Product	Cost	Reusable Alternative	Cost Difference
Forcep Sponge Rampley 25cm Disposable 06-273 Each	$7.41	$33.43	550% ▲
Forcep Adson Serrated Fine Disposable 06-355 Each	$2.28	$16.78	740% ▲
Scissors Dressing Sharp/Blunt 12.5cm 06-333 Each	$2.20	$12.52	570% ▲
Forcep Hartman Haemostatic Straight 06-244 Each	$3.45	$23.28	670% ▲

Figure 10. Cost breakdown of metalware medical devices found in cultural probe versus their resuable alternatives.

Theme	Group	Code	Hospital	Private Practice
Economic	Administrative Influences on Waste	Availability	1	2
		Initiatives	5	4
		Liability	1	7
		Memo	2	1
		Policy & Regulation	11	12
	Influences on Waste Production	Being Prepared	4	5
		Case-by-Case	3	16
		Cost	19	17
		Infection Risk	7	1
		Standardisation	3	14
		Sterilization	8	17
		Time	17	0
		Volume	8	0
	Types of Waste	Biohazard	9	6
		Consistent Waste	0	8
		Device	13	4
		Metalware	3	6
		Necessary Waste	6	11
		Packaging	6	3
		Paper	8	13
		Plastic	11	19
		PPE	24	6
		Procedure Pack	9	7
		Sterilization Fluid	0	0
		Sterilization Wipes	0	0
		Waste from Patient Care	0	0

Figure 11. Breakdown of econmoic codes.

Social Implications of Waste Management

The social influences of waste practices often were overlooked by much of the literature discovered for this paper. This gap in the research inspired an investigation into the participants' social responsibilities with their practice and the waste generated by it. Between both institutions of hospitals and private practice, participants considered 'Patient Care' equally crucial to them (Figure 12). Participants often emphasise that their waste practices become an afterthought, with 'Patient Care' and 'Staff Safety' becoming their priority when practising medicine. However, participants across both sides further identified an excess of waste generated from external forces other than just patient care.

"Okay. It's kind of like, patient safety is the absolute top priority, of course. Yeah. So I think that's why for a lot of stuff that it really does fall by the wayside."

- Douglas Holt on Patient Care

Two private practice participants often discuss 'Excess' waste as sourced from standardised single-use procedure packs producing too much-unused material that is then disposed of. Many of these packs include metalware and plastic single-use devices, contributing a large portion of the excess waste in private practices. Parsons continues to affirm this discovery in the hospital where many procedures specific to antenatal utilised single-use procedure packs, finding that roughly 50% of the contents would be wasted without use.

"All of the kits are single use. So they've got metal implements in them. Plastic ones as well. Oftentimes, most of them don't even get touched. But then again, they just have to get thrown out."

- Morgan Lemin on Excess and Procedure Packs

'Inconvenience' was also cited by hospital participants where excess waste was generated from poor processes that failed to accommodate staff needs or understand real-world situations. Beaven tells us that proper waste segregation often failed due to poor bin placement in their department. Because their department is so busy, hospital participants claim 100% of all 'Busy Behaviour' coding that any waste produced is often disposed of in the closest bin available to be worried about later. 'Frustration' often follows this finding, with Beaven highlighting that many of their medical devices and PPE are often individually wrapped, exacerbating the packaging waste problem.

"So you do find a lot of people just throwing whatever into whatever bin, because it's the first thing they get to kind of thing."

- Danielle Beaven on Inconvenience

Hospitals (70%) and private practice (30%) participants also discussed cautious behaviour as a waste source. Holt refers to their cautious behaviour originating from their uncertainty of a given diagnosis. For example, a patient could exhibit signs of a mild, easily treatable condition but could also be something more severe. This behaviour means that extra, often unnecessary tests are conducted, producing more unneeded waste. Holt also highlights that stigma is often associated with health, and many patients "do not

really want to have something touching them that has touched another person". Both Parsons and Lemin discuss caution as a result of being unsure about the sterility of something, requiring them to open new procedure packs that produce more waste.

"Anything that you might think you might have touched you just chuck and or somebody might, you know, father might have accidentally walked past and you didn't see him, but you assume he may have touch something that you contact with a new baby so that it gets touched. That would get chucked out."

- Martha Parsons on Caution and Infection Control

Theme	Group	Code	Hospital	Private Practice
Social	Forms of Unnecessary Waste	Duplication	5	0
		Excess	12	6
		Uncertantity	6	3
	Impacts of Healthcare	Infection Control	3	10
		Patient Care	15	14
		Priority on Health	8	3
		Staff Saftey	14	4
	Social Behaviours & Emotions	Apathy with waste	2	3
		Busy Behaviour	11	0
		Caution Behaviour	13	5
		Collaboration	7	2
		Comfort	0	6
		Communication	3	8
		Complacent	0	4
		Demand	2	1
		Effort	2	1
		Fatigue	3	0
		Frustration	4	1
		Inconvientent	6	1
		Personal Belief	1	1
		Stigma	1	1
	Waste Reduction	Consumer Demand	1	4
		Oppourtunity	2	7
		Technology	8	2
		Training	4	6

Figure 12. Breakdown of social codes.

Environmental considerations by health professionals.

It is clear that participants consider environmental factors the least in their medical practices at 24% (Figure 8). The literature reviewed for this paper reinforces these findings where there are only exploratory initiatives into how the medical field may become more environmentally sustainable. However, what is clear from the interviews and cultural probes conducted, is that the interviewees maintain personal, environmentally conscious beliefs that inform their practices. Opportunities were discussed with interviewees regarding how they might reduce their waste practices. While all participants discussed extensively using single-use devices 80% of the time over reusable (20%) ones in their practice, many suggested reduction methods involving more reusable medical devices and equipment. Private practice participants often discussed replacing paper barriers to beds and chairs with linen that could be washed for reuse. At the same time, hospital participants highlighted unique problems related to the hospital model, where either technology inefficiencies or excessive patient waiting periods were blamed for increased environmental waste.

“I think I’ve seen one unofficial recycling bins in one area of the emergency department. The way the bins work. There is normal bin for everything. And a clinical waste bin.”

- Douglas Holt on Waste Segregation

Figure 13. Stock cabients from cultural probe coded and labeled.

‘Waste Segregation’ methods were often observed extensively by hospital participants 65% of the time compared to their private practice counterparts. Both Beaven and Parsons claimed that much of their waste was correctly sorted into a range of bins for appropriate disposal, including recycling and soft plastics. However, Holt finds that their experience is the opposite and often fails to find waste bins other than those for general and contaminated waste.

Parsons claims that this practice is often informed by costs associated with contaminated waste disposal. Thus communication from management typically pushed for greater segregation of waste.

“So it’s quite expensive to have taken away. So there was always a drive to make sure that you only put contaminated waste.”

- Martha Parsons on Waste Segregation and Cost

In contrast, within the dental category of private practices, the cost of waste does not increase the use of the single-use device but reduces it as there is a large volume of patients requiring

medical devices. Shah tells us that for dentists, reprocessing metalware is standard practice within the industry as it becomes cheaper to reuse thanks to scale. Shah describes another success in the waste reduction where a community recycling program was implemented in their dental practice that cooperates with Colgate, which takes on the costs of recycling dental-related products.

This discovery represents a success in reducing environmental waste, telling us that once it is beneficial with cost, private practices become more receptive to products or services that reduce the impact of their waste.

“We autoclave quite a bit, like I’d say if I had to really put out a split, I’d say about 70% of the things that we use are autoclavable. And about 30% of the things are one time use only on the subject of recycling.”

- Sagar Shah on Waste Reduction and Sterilization.

Theme	Group	Code	Hospital	Private Practice
Environmental	Categories of Devices	Reusable	5	4
		Single-use	15	21
	Environmental	Environment	4	7
	Waste Methods	Disposal	15	12
		Incinerate	1	2
		Recycle	8	7
		Sharps	3	5
		Spatial Placement	3	1
		Third-Party Intervention	0	8
		Waste Reduction	5	13
		Waste Segregation	19	10

Figure 14. Breakdown of environmental codes.

LIMITATIONS

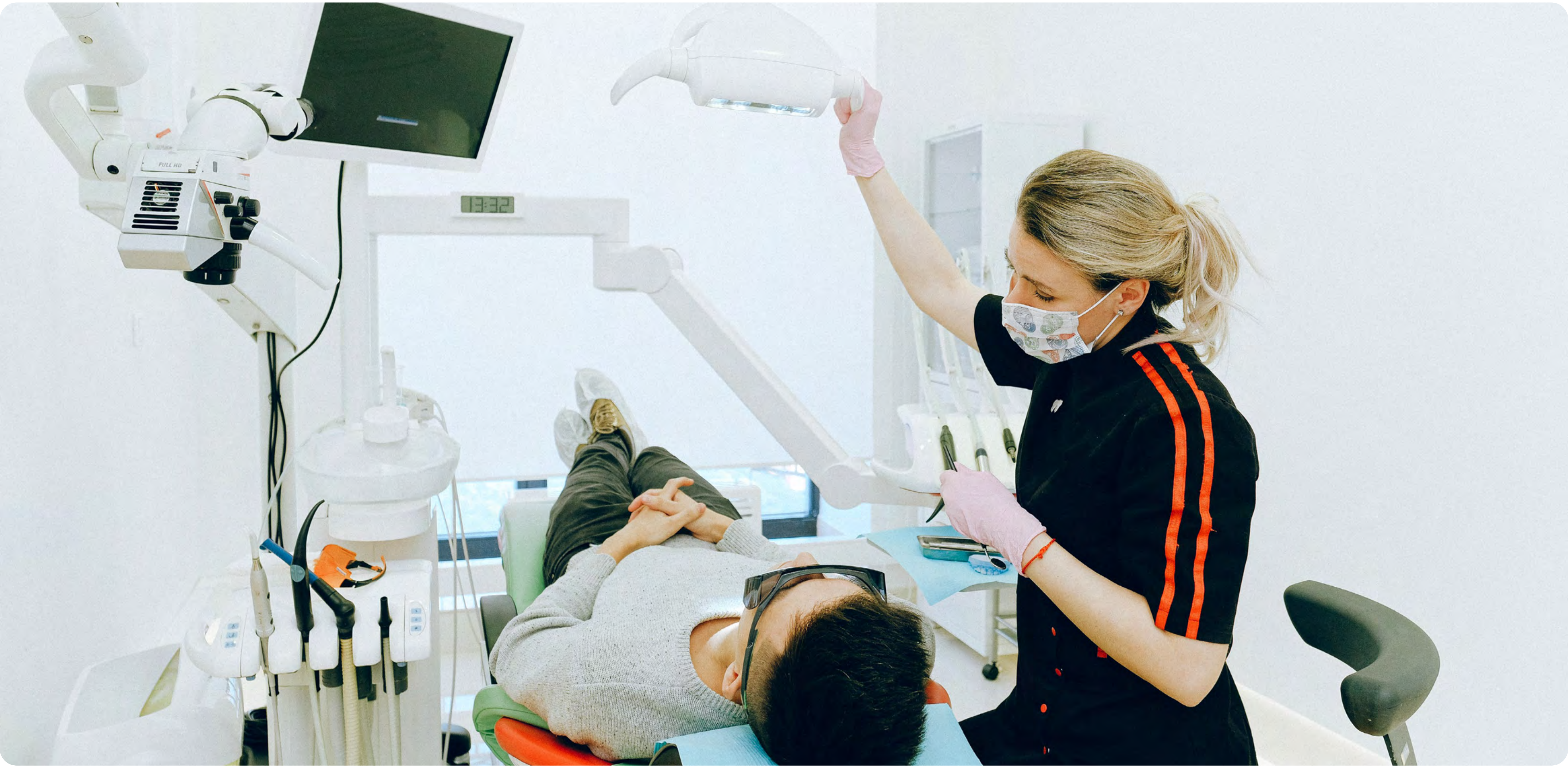
The sample size of interviews and the scope of the cultural probe impose notable limitations that should be considered when reviewing the results presented. However, as we have used Grounded Theory by deeply analysing qualitative data, the intended purpose for creating a new theory has been achieved regardless of the data analysis size.

Sampling biases may have influenced interviewees as the selection of participants was sourced from immediate networks available to the researcher. Participants of the interviews were geographically limited to South-East Queensland and Central Coast, New South Wales, Australia. Sampling bias, however, was limited by including participants that each contained significantly different areas of the experience, with an even split made between hospitals and private practice health professionals. The cultural probe was limited to a single general private practice in Fortitude Valley, Queensland, and only was completed by nurses employed by the practice without doctor intervention. Further limitations were introduced as responses to the response material remained low. Thus, the generated theory presented focuses on analysing the interviews primarily to reduce data noise.

SUMMARY

The research and findings explored the economic, social and environmental influences that dictate medical waste management practices within hospitals and private practice medical institutions. This paper intends that the findings presented would be considered informing design decisions for a product or service that will improve private medical practices concerned with medical waste to either reduce, reuse or recycle. The findings employed a grounded theory framework to offer a structured analysis of the transcribed interviews and cultural probes that will inform the design criteria. Economic, social and environmental influences were outlined during the coding process, each to be used to develop practical design criteria that will generate a design sensitive to this paper’s context.

DISCUSSION



INTRODUCTION

Medical waste is not the result of a singular issue. It is a complex tree of influences, including regulation, policy, tradition and human biases informing each other. For example, it was discussed in the literature review that the medical industry had trended away from the practice of sterilising medical devices for reuse in favour of a simpler pay-per-use model founded on the extensive use of single-use medical devices (Alfa et al., 2010; Kagoma et al., 2012). This model has become standard in much of the west as there have been noted concerns regarding costs and liability with reusable device reprocess (Alfa et al., 2010; Moultrie et al., 2015). While the literature has served the hospital environment extensively, there are still many unknowns when discussing private medical practices. Up to 82.4% of survey respondents from The Australian Bureau of Statistics (2021) often visited General Practices, whereas only 12.5% were admitted to a hospital. This disparity of minimum research with high admissions afforded a gap in the literature that has informed the research conducted by this paper. This insight leads the paper to ask, “how can health professionals remain economically, socially and environmentally sustainable while reducing medical waste disposal in their practice?”

The primary research of this paper aimed to develop a greater understanding of the medical waste management processes found in private medical practices. Compared with those found in larger hospital institutions’ practices, the research will help develop a breadth of understanding that will inform the design criteria for a product or service. As there was an identified gap in the research regarding the private medical practice, extra attention was taken to understand these smaller institutions, which informed this paper’s mixed methodology approach. Semi-structured interviews with six medical professionals split evenly between both forms of institutions emphasised specific literature findings and informed a richer secondary stage. In addition, the cultural probe was conducted at a Brisbane-based General Practice with nurses that further informed vital insights. The macro findings from the mixed-methodology were:

1. Patient Care is the top priority, and anything else, including the generation of waste, is secondary.
2. Cost directly influences medical waste practices.
3. Many Medical practitioners care about the environment in their personal life.

PATIENT CARE

The literature review discovered early that patient care and staff safety were paramount in the medical industry. The consumption of single-use medical devices became common in the industry after the threat of blood-borne diseases became a more significant part of the conversation in the 1980s following the discovery of HIV/AIDS.

Today, the practice of single-use devices continues to take precedent in hospitals and private practices, as reinforced by the research. However, while there is a valid argument for single-use medical devices such as needles and cannulas, the contemporary argument for other forms of waste, including metalware and protection devices, has become an economic issue. Many participants considered their waste excessive but considered it a necessary evil, as many participants are limited to the provided equipment. McGain et al. (2017), in literature, affirms this discovery where they were able to replace anaesthetic-related medical devices with reusable variants that reduced their waste considerably as well reducing costs—indicating that altering existing practices may produce a better outcome.

Primary research revealed essential discoveries that the paper’s literature review had not found. For example, hospital participants mentioned that the direct care of patients took up a large part of their time and, as a result, meant that the correct disposal of waste was often ignored. However, it is essential to note that private medical practice participants failed to mention time as a significant influence over waste management practices. Instead, the greatest influence over medical waste in private practices involved the individual cost of each medical device. Furthermore, all participants discussed that more significant amounts of waste were often generated as participants experienced uncertainty about the sterility of a given medical device, leading to an excess in waste. Medical professionals discuss liability in literature as the root cause of this reaction as many are trained to be risk-averse in their practice (Moultrie et al., 2015).

ECONOMICS

Economic influences have become the norm, dictating many waste management processes in the medical industry. With medical waste costing ten-fold that of general waste, it has become increasingly important for medical institutions to segregate their waste correctly (McGain, 2010). Participants interviewed in hospitals agree with the literature, with Beaven describing six separate bins for different disposal methods in their department. However, the participants of smaller private medical practices investigated tell us another story: the cultural probe demonstrates a single waste bin, and interviews go on to highlight a similar scenario.

Private medical practice participants highlighted their reliance on single-use disposable medical devices as participants regarded reprocessing reusable medical devices as a cost-prohibitive process in their practice. Citing that not only are the autoclaves required to sterilise expensive but so is the labour required to maintain the high level of care needed to ensure sterility of the devices. This economic influence is often the deciding factor in managing private medical practices. When the turnover of reusable medical devices remains low, it is often cheaper for the practice to pay-per-use through single-use devices.

RECOMMENDATIONS

The following section outlines key recommended designs and services informed by the literature review and key research findings. These directions aim to inform a future product or service that will help reduce the sustainability impact medical waste has on private practices.

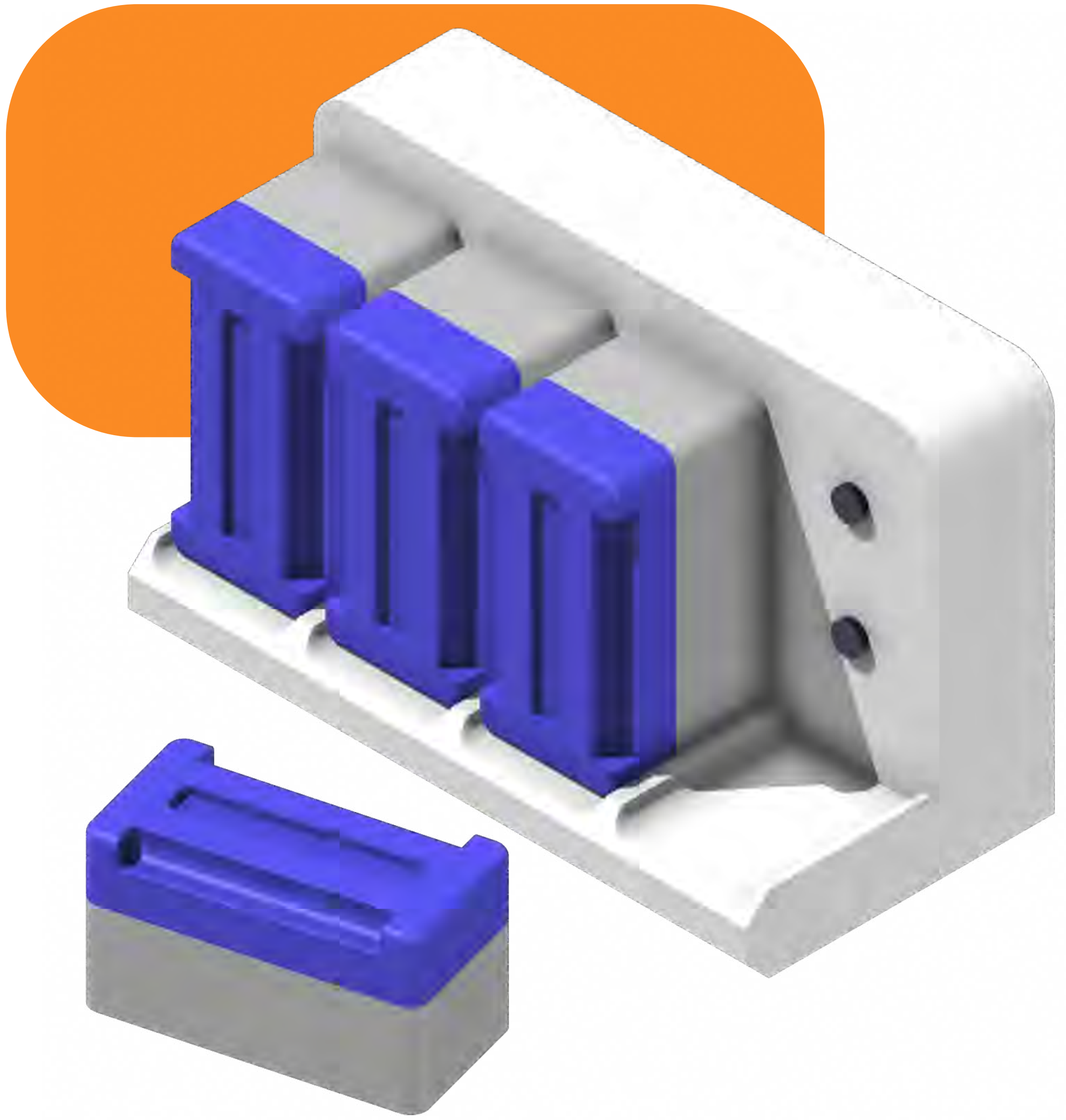
OPPORTUNITY 1: MODULAR AUTOCLAVE

The modular autoclave will resolve the key outlined issues found by research using modularity to adapt to a given private practice's needs. The modular autoclave intends to automate the sterilisation process as much as possible to reduce the costs associated with the individual machine cost and the labour required to maintain a traditional autoclave. Modularity is achieved by reinventing the procedure pack to be integrated with the new product. Each procedure pack comes in a standardised sealed container where the sterilisation process occurs. So that once a given procedure has been completed and the reusable metalware has become a-sterile, the doctor can place the instruments back into the autoclave procedure pack container and insert them back into the main machine. This is where a steam and pressure cycle will occur to sterilise the contents fit for future use. IoT systems will be integrated into each modular container to track usage and sterility to ensure patient care. The key functions described solving many issues found in private practices described to us during the research. Modularity and automation will be essential to reduce costs long term, as is vital in private practices. Streamlining the interactions with the machine will reduce the time taken to perform a task, which is essential, especially for commonly time-poor doctors. Smart technological integration ensures that liability concerns can be met so that sterilisation certainty of the medical instruments can be ensured.

- Modular
- Fully Automated
- Reusing medical devices.
- Zero Waste

Limitation and Considerations

The product will require a high degree of engineering involvement to ensure each component is compatible with stringent medical regulation standards set forth by AS/NZS 4187:2014 and AS/NZS 4815:2006. However, concerns lie within the modular function of the device as the pressure and temperature requirements to achieve medical-grade sterilisation are high, and any mechanism that interacts with the high-pressure system should be evaluated extensively. In addition, limits are present with the modular containers with how much each can hold, and appropriate considerations should be taken to understand what is needed to fit each one.



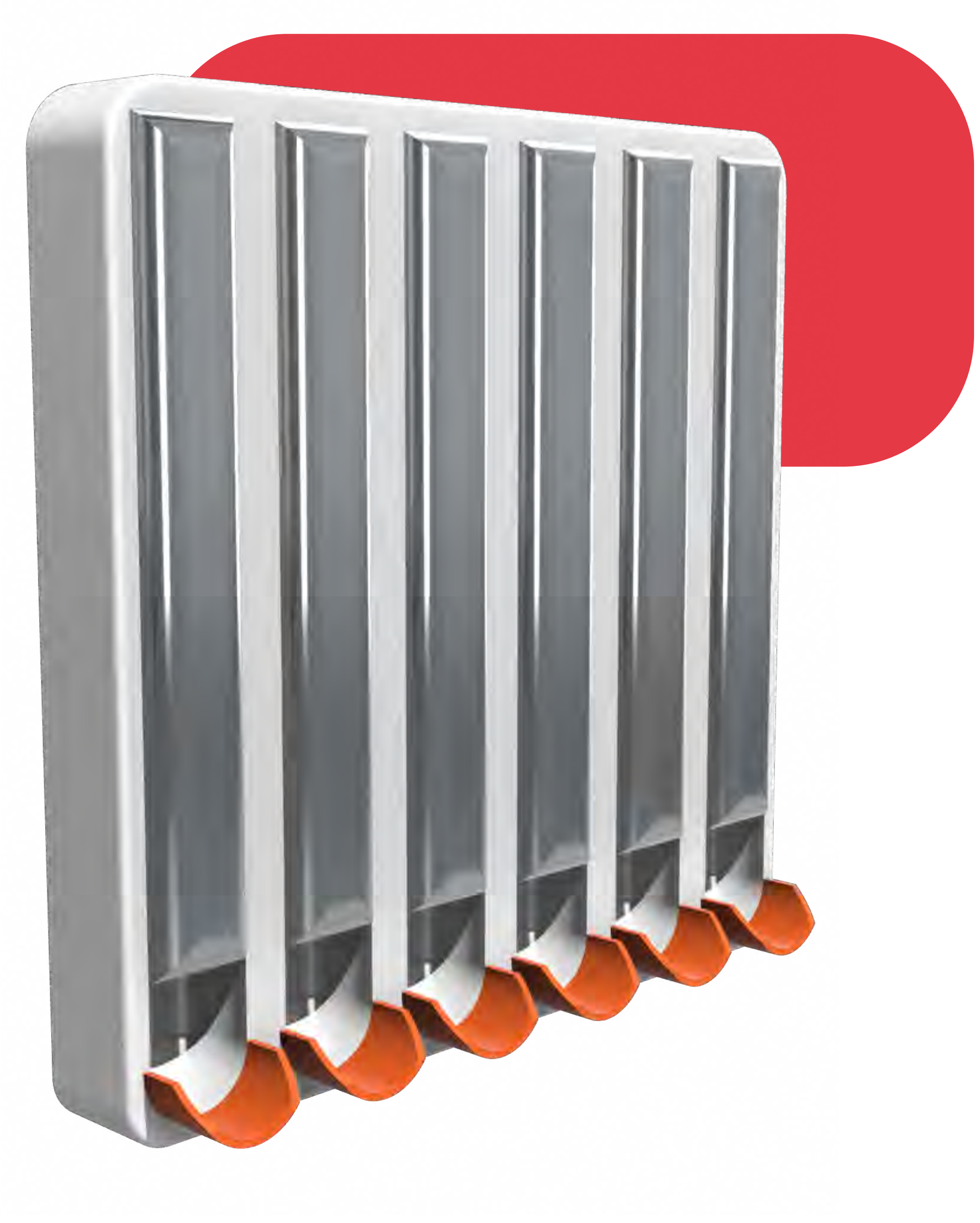
OPPORTUNITY 2: EQUIPMENT DISPENSER

An issue was identified in the research phase that, if resolved, could reduce the waste generation vastly by allowing medical professionals to *build* their custom procedure pack suited to a particular task. While participants often describe procedure packs as one-size-fits-all, the ability to pick and choose the correct amount of an array of equipment will be valuable to any medical institution. The equipment dispenser aims to solve just that, a wall-mounted device that allows an individual to request medical devices from metalware to bandages so that the health professional only exposes what is used to reduce waste. To refill the dispenser, cassettes of medical equipment can be placed into the machine by the medical facility's staff that arrive in purpose-built packaging that can keep a set of devices sterile from delivery to the device. The device relies on comprehensive standardisation of the equipment it carries, and as a result, key partners in the medical device industry will be critical to the product's success.

Limitation and Considerations

A series of services should be considered for the product to become viable. Manufacturing the cassettes received by private medical practices will be critical to the product's success. Another service should be considered for the dispenser where technicians could refill the product on a schedule set by the medical facility so that the long-term maintenance of the dispenser can be ensured. Finally, limitations may exist for the product as medical equipment can vary significantly in storage requirements. Thus, special considerations need to be taken into how much space the device intends to take up, mainly as some private practices may be limited in spatial footprint.

- Reduce waste generated.
- Use what you need.
- Service supported product.
- Wall mounted.



OPPORTUNITY 3: STERILISATION & WASTE SERVICE

Identified in the literature and primary research phase, a lack of appropriate disposal methods meant that many private medical practices discarded waste incorrectly. Another critical issue identified by the primary research was that the cost of sterilisation, often in smaller practices, outstripped the demand required to maintain long-term viability with running costs and labour accounted for. Thus internal sterilisation programs often became cost-prohibitive. The purpose of a sterilisation and waste service is to bridge the cost gap many smaller private medical practices cannot achieve when wanting to become more environmentally friendly. The service includes a series of purpose-built bins that will promote a pleasant sorting experience at the time of disposal. Bins will include those that will capture used equipment owned by the service and replace it with clean devices. Other bins include methods of recycling, soft plastic recycling and sharps and paper disposal.

- Service supported product
- Predictable costs.
- Capture and sort medical waste.

Limitations and Considerations

For this service and product to be viable, investigations into an appropriate distribution and service network will be required to enable facilities with the sterilisation capacity required to service an area. Limits are present in the type of waste the service can capture, such as general waste, which will be handled in the existing channels private medical practices have. It will be essential to explain the need to correctly sort their waste before disposal to reduce costs for resorting to misplaced waste. A method of education can be through the design of the bins themselves, and the effective use of design cues will be necessary to the overall product success.

PROPOSAL

INTRODUCTION

Private medical practices have the opportunity to reduce a significant portion of their waste that is often discarded each day. However, existing medical waste practices and future goals desired due to climate change are incompatible. Thus effective intervention action needs to be taken to improve the future health of the environment and its people. In addition, a valid concern for proposed sustainable practices exists as health professionals continue to place precedent on patient care and staff safety over potential sustainable strategies. However, this design proposal argues that these two competing ideas can coexist where we can maintain patient care and staff safety in the most environmentally, economically and socially sustainable way possible.

The following proposal addresses this paper's findings. It offers suggestions on how they might be implemented by design in a product of service that aids private medical practices in reducing their medical waste.

DESIGN INTENT

To develop a product, system or service that reduces the medical waste generated by a private practice while remaining environmentally, economically and socially sustainable.

OBJECTIVES

The following objectives extracted from the research findings of this paper will be maintained during the design process.

1. Enable, enhance or make the processes of either disposing or sterilising potential medical waste easier.
2. Provide a holistic experience that involves using both a product and a system or service.
3. Empower users and help promote a positive relationship with their waste management practices.
4. Include a human-centred design methodology for an enhanced experience.

PROPOSAL JUSTIFICATION

It is hard to justify the 8 billion tonnes of waste generated by the medical industry each year, rivalling the food industry as it grows. It is also hard to justify the healthcare system's expansion as it simultaneously generates environmental waste and betters the health of its population (Ordway et al., 2020; Wyssusek et al., 2020). Today, medical waste has become a concern internationally, where the impact has only exponentially grown, with COVID-19 causing a significant shift in how the industry perceives its waste (Andeobu et al., 2022). The focus on private medical practices is vital. The Australian Bureau of Statistics (2021) tells us that the average citizen visits a private general or dental practice far more frequently than they are admitted to the hospital. While many barriers are still present in the hospital and private medical practice, early

interventions discussed in the literature have shown promising results and should be considered with future interventions. However, as discussed in the literature review, it is evident that research often excludes the private sector and focuses on the hospital environment. The research presented here and the following proposed criteria aims to build a foundation that future design and literature can build upon when discussing opportunities for private medical practices.

CONTEXT

The target audience for the proposed solutions creates a diverse social context, as any proposed design solution must accommodate a range of demographics posing an inherent wicked problem. While many users will have an array of unique backgrounds, beliefs, interests and values, it is evident in the research presented that every potential user maintains a strong focus on patient care and wellbeing. This common trait will be necessary for proposed designs to understand deeply.

It is important to note that this design proposal and its research are based on data collected from Central Coast NSW and South Each QLD, Australia. This geographic bias presents a proposal through the lens of each jurisdiction's unique medical, legal and legislative constraints.

CRITERIA

The following section outlines critical criteria informed by the research discovered in this paper. The criteria should be considered in any design solution that is based on the context of the findings discussed.

Accessibility

The solution must appeal to private medical practises of varying sizes and financial means. In addition, the product, system or service should consider a wide range of demographics, each with varying needs and abilities.

Discoverability

It is essential for the product, system, or service to be easily understood and discoverable by its users. Special considerations with user testing and feedback will be essential to develop strong visibility, mapping and affordances that cue the user on the solutions functions.

Function

The product, system or service must perform its function with high reliability to become a successful solution. It is crucial to remain reliable as it must be considered that the solution may affect patient care and staff safety.

Aesthetics

Within the social context of medicine, it is essential to consider the aesthetics of a given product, system or service. The aesthetics should consider the intended purpose of the solution and present that to not only users of the solution directly but also patients to promote ideas of comfort, safety and reliability. Aesthetics must not be employed in a way that causes the user to feel uncertain or uncomfortable with the solution.v

Feedback

Effective and consistent feedback must be considered so that users can expect the reliability and certainty of an outcome. A high level of transparency in the solution function should be incorporated to help achieve this reliability. The effective use of audio, tactility, and smell should be considered when designing for the context of this proposal. The solution must not provide feedback that is unexpected by the user.

Sustainability

The product, system or service must not only be limited to environmental sustainability. However, it must also consider the effects the solution may have on the economic structure of private medical practice and the social implications that may occur for its users.

Regulation & Policy

As with all medical devices in Australia, regulatory approval and standards requirements must be considered when designing any product, system or service in response to the proposal. For example, a solution that will perform sterilisation procedures must adhere to Australian standards AS/NZS 4187:2014 and AS/NZS 4815:2006 and the international standard: ISO 17665-1:2006(en).

Limitations

Limitations exist for designers developing solutions for the medical industry. First, designers will have a limited perspective on the breadth of knowledge present in the context of medicine. However, this lack of experience may be mitigated with the practical application of user testing and feedback.

Designers will not have the practical knowledge and understanding of what it is like to diagnose, care and operate on a patient in any medical context. Challenges present in the medical setting may often be difficult to describe, and thus, the designer must understand that there is often a lack of clarity. However, actions can be taken to increase understanding by developing comprehensive partnerships with government health departments and localised private medical practices. In addition, it is clear from this study that many individuals in the medical industry have a passion for sustainability in their personal lives and have shown interest in applying that passion to their practice.

It is crucial for the designer to consider these limitations and should employ the design process with a human-centred design methodology to develop effective products that meet the strict guidelines and requirements, regulations and policy afford. Detailed prototypes must be developed during the design process, which can be cost-prohibitive and time-consuming. Regulatory approval must also be acquired, which, in addition to the design process, will be expensive and time-consuming. As such, the designer needs to work closely with specialised engineers, medical professionals and regulatory bodies to achieve an effective design outcome that is considerate of the time and costs associated.

SCHEDULE

PHASE 1
Week 1-2

- Design Opportunity Exploration.
- Concept Ideation.
- User Reserach.
- SWOT, PESTLE analysis.

PHASE 2
Week 3-5

- Direction Discovered
- Refine Brief with direction
- Begin Prototyping
- Specify required standards.

PHASE 3
Week 6-8

- Design Detail Ideations and Development
- Prototyping & User Testing
- Material and Manufacturing Discovery
- Brand Ideations
- Design Freeze

PHASE 4
Week 9-12

- Final Prototype
- Business Case Plan
- Bill of Materials
- Presentation Material

SUMMARY

Medical waste is the direct result of patient care and staff safety. However, It is evident in literature and the primary research that medical waste has become pervasive across the medical industry. Additionally, it is apparent in research that existing practices promote the excessive and unnecessary disposal of devices and equipment ending up in landfills, which often may not have aided a patient's health. However, discussions with health professionals across hospital and private practice environments have proven a personal desire to improve their waste practices and become further sustainable.

This report has endeavoured to capture and contrast the existing medical waste practices between hospital and private medical practices. The literature review built a foundation of knowledge upon which primary research was based. Evidence found in the research was used to construct a comprehensive discussion under the lens of sustainability, including environmental, economic and social inside private medical practices. Finally, a proposal was built upon this found knowledge developed to add to the conversation of medical waste and develop informed solutions. Key takeaways from the literature and primary research include:

- Medical waste is a wicked problem, informed by many complex social and economic factors

- There is a desire from health professionals to reduce the waste impact has on the environment.

- Existing solutions have proven incomplete and often fail to be sensitive to patient care.

The following section justifies a proposed intervention that attempts to amend the issues found during the course of this report.

JUSTIFICATION

INTRODUCTION

modClave, the first of its kind, incorporates industry-standard sterilisation technologies and strips them down to their core components, recontextualising the autoclave for medium to large-sized medical clinics. The autoclave has been an effective tool in reducing the risk of infection among patients. Steam is used as a method of sterilisation, exposing instruments to required temperatures and pressures over a specific amount of time (CDC, 2019). However, the traditional autoclave can be cost-prohibitive as it often requires extra support labour to manage and maintain the incoming and outgoing instruments. modClave aims to change this by merging several technologies into a modular system that functions as both the method of storage and sterilisation.

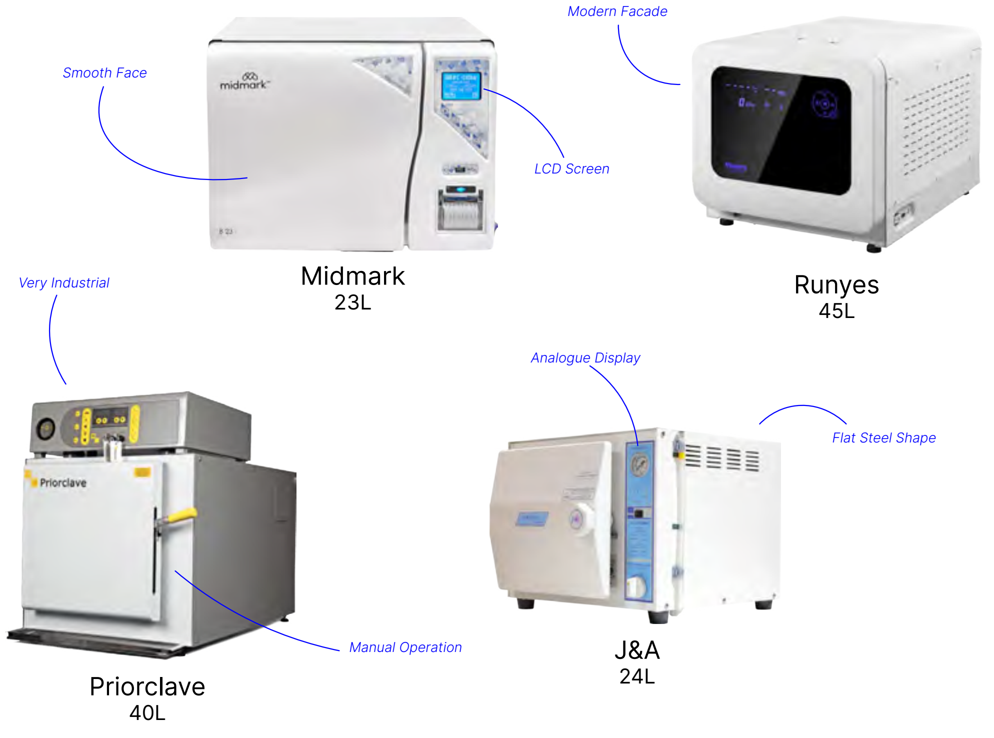


Figure 14. Example of existing desktop sized autoclave machines.

FURTHER RESEARCH

Additional research into autoclaves revealed that a wide range of form factors and sterilisation techniques exists, dependent heavily on the context and use case. While this project's scope focuses on the desktop, more significant portions of the autoclave industry focus on room-sized autoclaves, often used in hospitals and large laboratories. As pictured in figure 14, it is clear that the autoclave options available to small to medium-sized medical clinics today are often high-capacity units that offer basic but technical interfaces. Without proper training, many of these devices may be confusing and intimidating to operate. Limiting the users to personnel who are trained in the safe operation of their autoclave.

While the brands outlined above represent the leading competitors in the marketplace, innovation has become stagnant, where new iterations often mean a new facade and a coat of paint. The fundamental interactions remain static between updates, and loading and unloading instruments continue to be cumbersome. The result means much smaller private office- and community-based medical clinics defer using an autoclave in favour of single-use instruments. This presents an opportunity for intervention and improvement of existing processes when focusing on the context of medium to large-sized practices whose needs are often unmet, as proven in the previous analysis and findings section.

Existing autoclave manufactuers include:

- PRIORCLAVE
- MIDMARK
- RUNYES
- J&A
- TUTTNAUER
- WEGO
- STEELCO
- GALBINO

Sterilisation

An autoclave's sterilisation process involves a combination of steam, heat, pressure and time. The core principle of steam sterilisation is to expose the contents of an autoclave to direct steam contact at the required temperatures and pressure. While heat and steam's contact with instruments is what sterilises the contents of an autoclave, pressures build as a function of the increasing heat in the steam to kill microorganisms (Rutala et al., 2008). In figure 15, the Centres for Diseases Control and Prevention (CDC) 2008 released a document outlining the exact temperatures and time required to reach an acceptable confidence in sterilisation. The highlighted row in figure 15 is the ideal goal for the proposed intervention.

Technology	121°c	132°c
Gravity Displacement		
Wrapped Items	30min	15min
Textile Packs	30min	25min
Wrapped Utensils	30min	15min
Dynamic-air-removal	121°c	132°c
Preferred: **Wrapped Items**	**N/A**	**4min**
Textile Packs	N/A	4min
Wrapped Utensils	N/A	4min

Figure 15. Minimum Cycle Times for steam sterilsi-ation adapted from Rutala et a. (2008)

Standards

The Royal Australian College of General Practitioners (RACGP) outlines in _Infection prevention and control standards_ the types of cycles desktop autoclaves can run in three classifications (RACGP, 2014). As set by the Australian Standard (AS/NZ 4815:2006), which governs autoclaves used in private office- and community-based practices, the classes include N, S and B.

- Class N: Covers autoclaves that do not have an active drying cycle.
  - Cannot effectively dry and ensure sterility of packaged items.
  - Not suitable for private office- and community-based practices.
- Class S: Autoclaves that have an active drying cycle.
  - Suitable for most metalware instruments without hollow features.
  - Adequate for private office- and community-based practices, but not dentists.
- Class B: Utilises one or more vacuum stages to ensure deep steam penetration.
  - Suitable for all packaged instruments, including instruments with hollow features.
  - Often the only option a dentist has in their practice.

CONTEXT, SYSTEMS & SCENARIO

People

While the focus of this project was to improve the sustainability of the reprocessing system, the human experience has been considered in great detail. This is important because the desired outcome of the intervention is to reduce the need for extra staff. Meaning that doctors and nurses, whose roles often exceed managing an autoclave, will have to be able to interact directly with the proposed interventions interface.

Activities

The primary purpose of the autoclave is to sterilise reusable instruments as a method of infection control so that they may be safe for continued use over the instrument's life. Often the autoclave is reserved for higher-value items that would be too great a financial cost to dispose of after a single use. The steps required to sterilise a soiled instrument are linear and require a series of well-documented steps to restore complete confidence in the instrument's safety. Often this process involves:

1. Removing any debris and cleaning the surface of instruments.
2. Packaging in air-tight plastic wrappers with appropriate labelling.
3. Sterilising with the use of an Autoclave.
4. Storing instruments for later use.

Context

Existing autoclaves require external infrastructure to support their safe and effective operation. Requiring a separate space to support the use of an autoclave can often be difficult for many smaller medical clinics, whose turnover of instruments may be mild compared to larger medical practices. Figure 16 offers a recommended layout for equipment reprocessing, where the autoclave is just one part of a more extensive system.

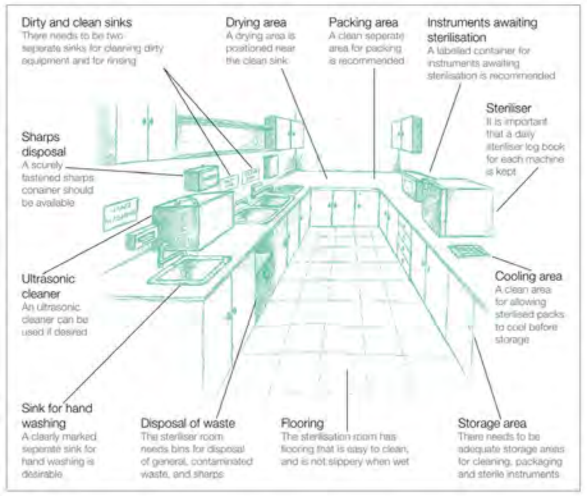


Figure 16. Suggested processing area design and layout, extracted from RACCGP (2014)

The proposed intervention will be directed towards mid to large-sized general practices and other office and community-based medical practices. Targeting institutions that may need help to set aside a custom-fitted room to support a traditional autoclave. As discovered in the analysis and findings section, the use of autoclaves or other reuse methods is often ignored in favour of cheaper, single-use options. Thus the intervention should have a low barrier to entry with minimal setup, training and overhead costs. The modClave itself will need to be professionally installed and may need minor modifications to cabinetry to allow for freshwater into the device and the wastewater expelled after a cycle. Within this context, the device may be left unused for extended periods as many patients often do not require surgical care that requires instruments. Thus the device should be able to remain on standby and ready for use at a moment's notice. In medical practices, sessions often last fifteen minutes at a time, reinforcing the need for quick action from the doctor and fast reprocessing by the intervention. This time constraint must also be considered in the product design as any confusion can quickly lead to frustration by the user. Space is also often a valuable resource in some clinics. Thus the ability to store devices compactly will be desired.

SCENARIO

modClave

1 Cleaning

1. The doctor or nurse may insert their used module back in to the desktop unit of the modClave, where it may begin a cleaning cycle.
2. This cycle follows the a strict linear set of steps, that is continually monitored by the computer to ensure quality.

2 Use

1. For a doctor or nurse to retrieve a module from the desktop unit, they will ensure the it's cleaning cycle has completed and then they may pull the module from the unit and take it to the procedure room.
2. After opening the module, it will trigger a flag electronically that can only be reset after a successful cleaning cycle has completed ensuring infection control. This flag is displayed to the user as notices on the screen and a series of audio tones for any subsequent opens of the module.

Traditional AutoClave

1 Pre-Cleaning

- Following procedure, quickly wipe any soil from the used instruments
- Package instruments in container directly to cleaning department. Otherwise let soak in water and detergent until cleaning is possible.

2 Cleaning

- Hand wash instruments in 'dirty' sink or place used items in an ultrasonic cleaner.

3 Rinsing & Drying

- Rinse all instruments with hot water, drain and hand dry with cloth.

4 Preparing

- Package instruments in provided packs. Sealing the instruments inside.
- Label packaging with date, lot number, etc.

5 Load Sterilser

- Pack your autoclave up to its maximum challenge load, ensuring it's contents are seperate and only loosely in contact.

6 Sterilisation

- Check settings and status of the autoclave.
- Run cycles as directed by the autoclaves manual.
- Record details of the load in to logbook for later inspection.

7 Unload Steriliser

- Remove the load from the steriliser, placing them in a clean space.
- Inspect load for any defects and fail the whole if items appear irregular.

8 Document the Cycle

- Take note of actions from each stage, including information of the loads contents, time of day, and other relevant information that may help investigations at a later date if required.

9 Storage

- When cool, store sterile instruments in a clean area away from dust or moisture according to date of last sterilisation.

PRODUCT DESCRIPTION

The proposed intervention, the *modClave* is a desktop medical appliance that is comprised of two major components, the desktop unit (DU) itself and the individual modules that connect to the DU. The modules are a direct replacement for single-use procedure packs, as pictured in figure 16, where instead, reusable metalware instruments can be stored and sterilised within the module. The DU can accept up to three modules where it can provide the resources necessary to complete a Class B sterilisation cycle, as outlined in AS/NZ 4815:2006 standard, on its contents.

Who is it for?

The modClave has been designed to help reduce the medical industry's disproportionate environmental impact on its community and its people. Specifically, the modClave appliance is directed towards general practices and other office and community-based medical practices. Where the Australian Bureau of Statistics (2021) finds that populations are more than eight times more likely to visit a general practice or dental professional than a hospital. However, as discussed in the literature review, it is clear that meaningful research in private practice remained low to non-existent in Australia. Thus, the modClave was developed after a series of interviews and a cultural probe in a local private practice.

What pain point does it solve?

It is clear from the research findings that the two core catalysts of medical waste are time and cost. Doctors and nurses, especially in the hospital setting, are often time-poor and are frequently preoccupied with the patient's health rather than the waste that results from care. Cost is then most commonly cited by those within private practices, where it is discussed as the reason many clinics will prefer single-use equipment as it is safer and cheaper to manage at their scale. These two functions of waste, time and cost are at the core of the modClave.

We can reprocess reusable instruments without any user intervention by removing the need for labour-intensive tasks to prep and process equipment through advanced technology and automation. This degree of automation removes the need for another staff member to prep and process instruments via the traditional methods discussed. Not only does it remove the need for expensive labour, but it also reduces purchasing of single-use instruments, leading to a healthier environment and a further reduction in cost. By extension, with the advancement in design, time is saved, and the module becomes a part of the patient's care and not something that needs to be sought after the fact.

Technology

The technology present in the modClave designs incorporates existing technologies discussed into a single package that can ensure the sterility of an instrument.

Desktop Unit

The combination of a boiler for steam, a vacuum and a water pump inside the desktop unit performs the bulk of the required cycles that will clean, dry and sterilise the instruments inside a single module. During a cycle, direct connections to data streamed from the module are analysed to ensure high quality so that, in real time, users and service technicians can diagnose any issues. A simple user interface was incorporated in the final design, with an LCD display and map.

Module (each)

While the module remains basic compared to the desktop unit, it contains critical pieces of technology that help the intervention maintain a high level of quality. As part of one of the device's cycles, ultrasonic transducers inside the module act as an ultrasonic cleaner to augment the cleaning process for greater infection control. Temperature and pressure sensors are littered throughout the module, passing data to the desktop unit for real-time analysis. A simple monochrome display is employed on the front of the module to display the status of its contents. Indicating whether the device has been opened since its last sterilisation cycle, reducing chances of cross-contamination. Advanced insulation is used extensively as a barrier between the pressure vessel inside the module containing the instruments and the exterior plastic shell.

Figure 17. modClave: Desktop Unit and 3 modules with 1 unplugged.

Aesthetic Inspiration

As the world becomes more united in causes such as climate change and environmental destruction, people today are becoming more interested and driven in how they might make a change themselves. This social drive has become a point of difference for many businesses now attempting to do their part and appeal to a broader range of people. This effort can now be seen in general practices where new clinics are instilling nature into their practice (Figure 18). These found qualities are what the modClave aims to achieve with its aesthetic design choices. A modern, clean aesthetic is often preferred, and nature is reflected by representations of steam in motifs that can be seen around the intervention.

Figure 18. New general practice found in Prahran, VIC

DESIGN DETAILS

Regulatory & Standard Conformity

The modClave has been designed to solve many of the regulatory and standards requirements set forth by the Therapeutic Goods Administration (TGA). The primary Australian standard that applies directly to the proposed intervention is *Reprocessing of reusable medical devices in health service organisations AS/NZS 4187:2014*. Briefly, the document outlines critical actions that should be taken when reprocessing equipment, such as:

1. Clear separation of clean and contaminated equipment when reprocessing.
2. Water monitoring to ensure quality.
3. Sterile stock should be stored in compliant locations.

The TGA defines medical devices that reprocess equipment as **Class IIb**, which is categorised as moderate-high risk (TGA, 2022). Thus, the intervention must adhere to the _Essential Principles_ that are legislative requirements to complete a conformity assessment certification before it may be included in the Australian Register of Therapeutic Goods. Key pillars of the proposed essential principles include:

- Design and construct according to safety principles and risk mitigation.
- Develop solutions that are state-of-the-art and best practice.
- Ensure that the benefit(s) of the device outweigh its risks.

Material Selections

Acrylonitrile-butadiene-styrene (ABS) has been used for exterior parts across both the desktop and module for its inert and impact-resistant properties. While the sterility of these exterior pieces is not critical to the intervention's function, it is important that they are easily cleaned and can maintain a long service life. However, the manufacturing of these components will need to comply with Australian and international standards, such as ISO 13485:2016, ISO 10993-1:2018, AS/NZS 3551 and AS/NZS 2500, that the TGA approval will be achievable.

Stainless steel has then been used for any metallic parts presented in the device. A common material found across the medical device industry such as traditional Autoclaves, medical instruments and ultrasonic cleaners.

Cleaning Cycle

The modClave follows several steps to ensure the highest quality of reprocessed instruments made by the device. These steps must be completed successfully in sequences before they may be considered sterilised and fit for use. The steps are as follows in this order.

1. Pre-cleaning Cycle. High-pressure water is ejected from both nozzles internally to remove any large residue.

2. Ultrasonic Cleaning. Water is filled within the module, and ultrasonic transducers inside the module run for 60 seconds to remove any fine particles.

3. Cleaning Cycle. Again, fresh water is blasted against the instruments to remove any remaining particles.

4. Autoclave Cycle. A light vacuum is pulled, and steam at 132 degrees Celsius is circulated through the module's vessel for 4 minutes to achieve complete sterility as per the recommendation outlined in figure 15.

Desktop Unit

Figure 19. Desktop Unit.

Installation

Installation of the desktop unit requires minimal professional setup, where modest carpentry and plumbing work may be necessary to aid the entail setup of an input and output hose. The input hose and its water may come directly from the water mains. However, as outlined in AS/NSZ 4187:2014, it should be monitored. The practice should already have achieved this, therefore it may be a manageable burden.

Figure 20. Rear I/O of the modClave Desktop Unit

Ergonomics

The desktop unit and its modules have considered the ergonomics of its potential users. Prototypes have been used during the development process to explore configurations of interfaces, unit dimensions, and angles of screens and buttons. Multiple forms of feedback have been used in areas where the correct operation is required, including using sound, colour and light patterns as methods to convey similar information to the broadest range of users effectively.

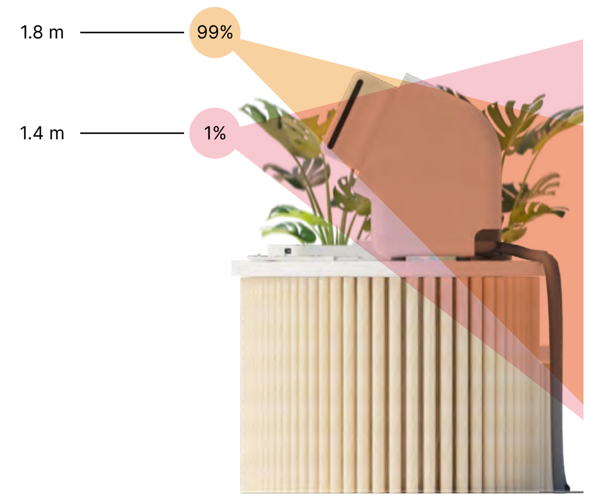


Figure 21. Limiting Users by Height superimposed over modClave. Adapted from Tilley and Associates (2001)

Display

The screen interface on the desktop unit comprises an LCD and a touchscreen digitiser. The screens function displays relevant real-time and historical data such as the temperature and pressure over time in a given cycle, current boiler status, estimated completion time of a current cycle and further debugging and maintenance information (Figure 22). However, the display is intended to be seldom used in regular operation, where the buttons below give the user all the controls they need to operate core functions.

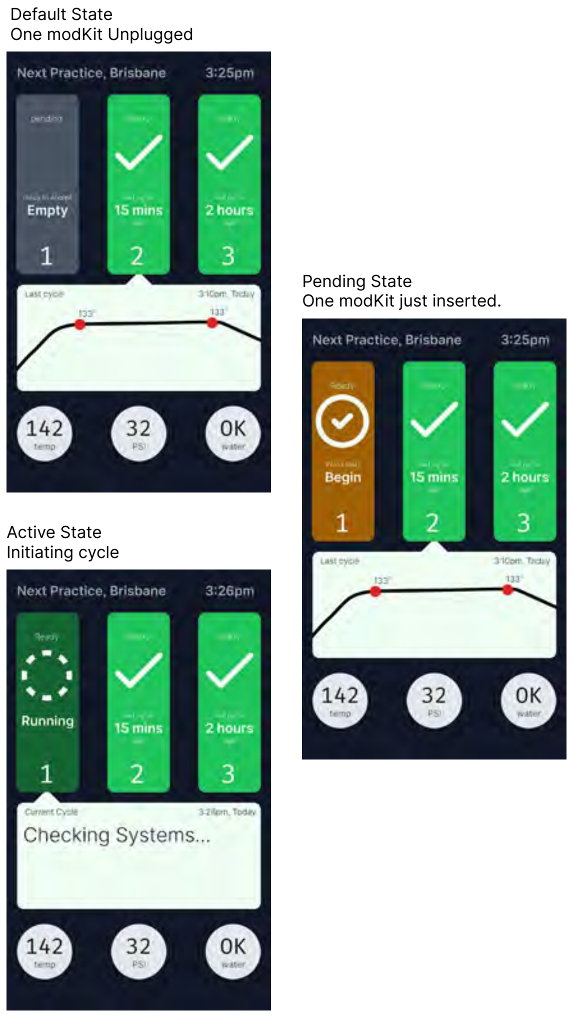


Figure 22. Screen UI of the Desktop Unit

Physical Controls

The buttons below the screen interface give the user instant control over a cycle at the press of two buttons. For the typical user in regular operation, these buttons fulfil the needs effectively and with minimal training. Where the top row of buttons is mapped to each module, the user may select their module and start a cycle with the "run" button or stop a current cycle with the "stop" button.

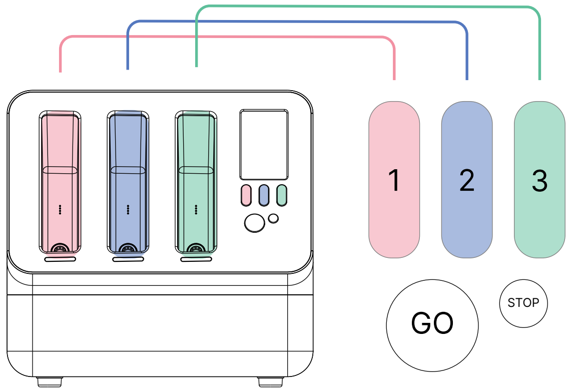


Figure 23. Button mapping diagram

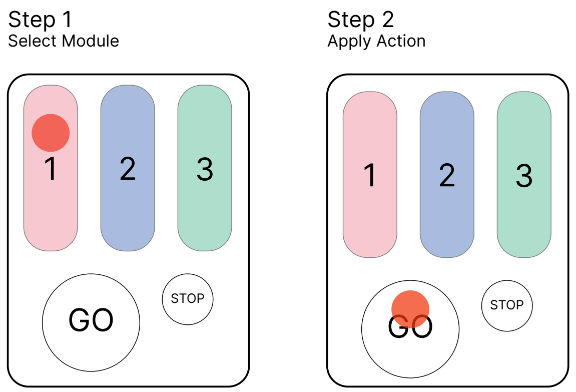


Figure 24. Button use matrix

Indicator Lights

Translucent polycarbonate (PC) is backed by LED lights that, at a glance, can indicate the status of a given module. Controlled flashing and colours are used to convey information which includes which stage of the cycle is running or if there is a fault.

Figure 25. Rendered close up of lights on desktop unit

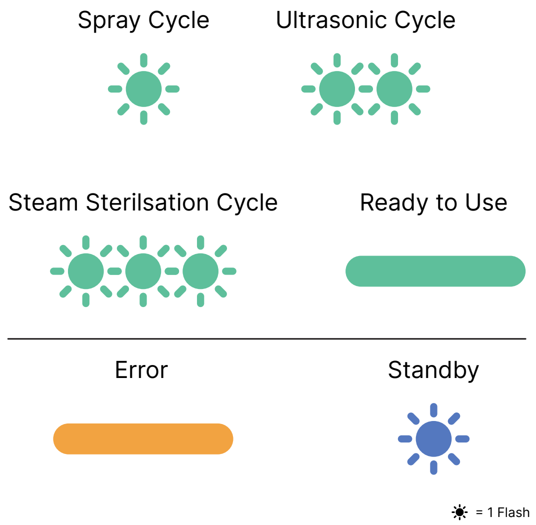


Figure 26. Light Symbol Matrix

Diagnostic Platform

While there remain physical interfaces on the modClave for staff to control functions daily, a web platform enables more precise control and analysis. Reserved for administrators and service technicians, this platform on the local intranet offers a way for trained individuals to fine-tune the settings of specific internal functions and review historical data for analysis and reporting purposes.

Figure 27. Diagnostics Platform for Provider. Adapted from Grafana.

modKit (Module)

Figure 28. modKit layed out on a table.

Monochrome OLED Screen

The module's electronics monitor and display, via the OLED screen on the front face, the sterile status of the container. This display shows if the unit has been sterilised - if it has been opened, the contents are no longer considered sterile. This is crucial to the success of the modClave as infection control is at the core of every medical professional's training.

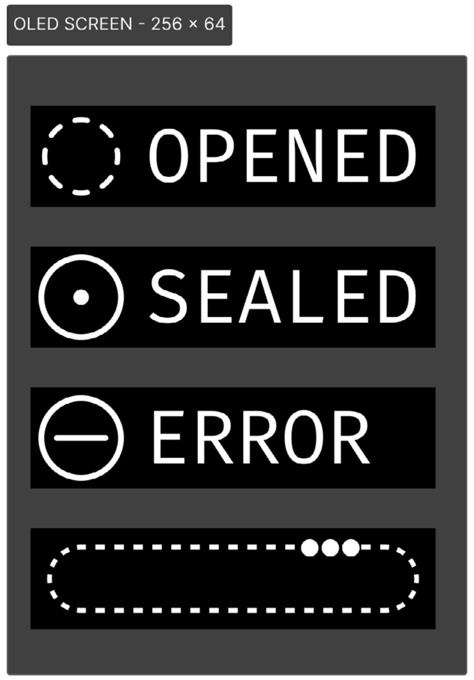


Figure 29. OLED Screens from Figma

Release Mechanism

Two key touch-points hold the lid on. Firstly a detachable hinge at the back that mates with the module body provides tension and helps apply a strong seal when closed. Lastly, a mechanical pull tab is located within the lid that releases on either side of the lid when pulled open. The tab is positioned away from the device and requires opposing forces to open the lid. During a cleaning cycle, this mechanism is locked from a solenoid within the module, so unplanned opens may not happen while under pressure and heat.

Figure 30. Lid Mechanism through a transparent shell.

Instrument Caddy

The instrument caddy that holds the metalware instruments utilises a series of tabs along two ribs that force the storage of instruments to be open when they are placed back within the device. Having the instruments open partially will increase the success of a cleaning cycle where any residue may build up inside instruments during use. The caddy may be replaced with different configurations to support different instruments.

Figure 31. Instrument Caddy with Instruments

Sensors, Transducers & Electronics

Internally the module is fitted out with various temperature and pressure sensors, ultrasonic transducers and low-power electronics to achieve its reliability goals. During a cycle, sensors capture internal pressures and temperatures to log the device's performance. If the desktop unit sees discrepancies, it may then be quickly reported to administrators and services technicians so that the quality required for this medical device may be achieved and maintained.

As part of the sterilisation process, an ultrasonic cleaning cycle involves submerging the instruments in water. Then, we can ultrasonically clean the instruments using the transducers for a deep and thorough clean.

Figure 32. Exploded view of the modKit

DESIGN PROCESS

DISCUSSION

The medical profession is highly risk-averse and is often cautious when introducing new techniques and technologies. These prejudices, in combination with the discovered limitations on time and financial freedoms, many health professionals experience. The opportunity to advance practices entrenched in medical history for the environment's benefit often takes time and effort. Thus the successful integration of the modClave requires deep consideration of the abovementioned issues and the ecosystem it hopes to reside within.v

Sterilsation as a Service

The autoClave's success with small to medium-sized clinics, which are often constrained by financial factors, lies within the business model the autoClave has accepted. Sterilisation as a service (SaaS) has been preferred for the modClave so that clinics may lease the product on term contracts, ensuring that anyone who wants a modClave can use one without the burden of high upfront costs associated with complex medical devices. From the service perspective, a health clinic may lease as many devices as they require, and the provider will outline a service-level agreement (SLA) that offers continual support. Thanks to the advancements in technology found within the modClave, the provider can remotely monitor each modClave, where reports and diagnostics information may be analysed so that preemptive and swift reactionary support may be applied, ensuring the reliable uptime of a single modClave. A few points outlined in an SLA may include the following:

- The modClave will have at least one (1) module bay ready to sterilise during the business hours of the clinic it resides within.

- The modClave will be remotely monitored for quality assurance, and service technicians will be dispatched within 48 hours if issues arise.

- Defects discovered in regular use of a kit will result in the replacement of the defective kit for service and repairs at the provider's cost.

- Liability will be the responsibility of the provider of the modClave.

For the long-term viability of the modClave would be the quality material, manufacturing, and engineering techniques must be employed so that the modClave is as reliable as possible, ensuring the support costs do not outweigh the SaaS income. Strict conservative benchmarks for performance will be set in place to resolve the liability concerns of the provider so that anything outside of expected operating parameters will be considered defective and replaced.

The benefit of the proposed model will be that health professionals will be able to develop a sense of reliability and confidence in the machine as all servicing and monitoring may be done by the provider and not their staff. This, as discussed in the analysis and findings, is preferred by health professionals who are often concerned with liabilities associated with health care and practices that may introduce more chances of legal

exposure. This concept of passing on liability and indemnification is already commonplace in the medical industry, such as in single-use instruments where the manufacturer would be held accountable for any issues, and thus is compatible with existing practices.

Ecosystem

The primary goal of the modClave's design was to be as frictionless as possible so that it may work in line with existing practices found within medical clinics with minimal training. This consolidates standard single-use procedure packs into a reusable kit that is self-sterilisable after each procedure. This benefit is that it reduces the load on waste streams where metalware instruments are often discarded after a single use, expelling metals, plastics and chemicals into the environment. A reduction of labour occurs when extra hours are no longer required to process reusable equipment, allowing for repurposing funds within financially constrained practices. Additionally, reliance on international supply chains to serve the local populations is reduced, ultimately lowering the impacts international shipping has on the environment.

Adaptability/Compatibility

As a part of the frictionless ethos of the modClave, the intervention also allows for adaptability in the types of instruments it can reprocess. This ability to adapt allows various compatibilities with instruments of varying sizes and shapes. While the caddy pictured (figure 31) is suited for a few sets of scissors, forceps and tweezers, there are opportunities for practices to customise the layout of the caddy to support alternate devices. For example, if a dentist wished to use the modClave to reprocess their dental drills, an alternate caddy that is specifically designed for the drill for the most optimal care could be used.

CONCLUSION

Waste in the medical industry directly results from providing patients with care and staff safety. However, it is clear from the research discussed earlier in this report that much of this waste is excessive and has grown to become a blight upon a medical professionals' communities. With a shift in the industry starting in the 80s, as the west was battling a homophobic HIV/AIDS epidemic, the medical profession began relying much more heavily on single-use plastics to fight infection opportunities (Laustsen, 2007). Today, the practice of single-use medical devices and plastics has become its own epidemic. The medical industry now produces more than seven billion tonnes of waste yearly (Ordway et al., 2020).

As highlighted in the literature review, it is clear that there needs to be more attention given to the needs of general practice and private office- and community-based medical clinics. Importantly, ABS (2021) reported that respondents were seven times more likely to visit one of the clinics than a hospital, highlighting the significance of this report. This gap in the research leads to this report's primary research phase. The findings of which reveal to us that there were indeed differences between the hospital and private practice environments. Finding that hospital staff often cited time as the leading factor of poor waste practices, whereas private practice interviewees claimed the cost was their most significant concern. However, it was clear that all participants practised good waste management practices in their own lives, thus suggesting that the environment is at fault, not the individual.

Throughout this project, investigating waste in the medical industry, this report and by extension its applied component has resulted in the modernisation and recontextualising of an existing platform (autoclave) so that it may better serve an often under represented portion of the medical industry. By understanding the issues medical professionals have in general practice and private office- and community-based medical clinics we have better suited the autoclave platform for their needs. The modClave, consolidates the findings of this report in to a service-based intervention that not only reduces the environmental waste a medical practice produces but also its economic and social waste where labor costs be put to providing better patient care.

REFERENCES

Abdul-Rahman, F. (2014). Reduce, Reuse, Recycle: Alternatives for Waste Management. 4.

ACSQHC. (2019). AS18/07: Reprocessing of reusable medical devices in health service organisations. Australian Commission on Safety and Quality in Health Care. https://www.safetyandquality.gov.au/sites/default/files/2019-12/as1807_reprocessing_of_reusable_medical_devices_in_health_service_organisations_december_2019.pdf

Alfa, M. J. (2013). Monitoring and improving the effectiveness of cleaning medical and surgical devices. American Journal of Infection Control, 41(5), S56–S59. https://doi.org/10.1016/j.ajic.2012.12.006

Alfa, M. J. (2019). Medical instrument reprocessing: Current issues with cleaning and cleaning monitoring. American Journal of Infection Control, 47, A10–A16. https://doi.org/10.1016/j.ajic.2019.02.029

Alfa, M. J., Olson, N., & Al-Fadhaly, A. (2010). Cleaning efficacy of medical device washers in North American healthcare facilities. Journal of Hospital Infection, 74(2), 168–177. https://doi.org/10.1016/j.jhin.2009.06.030

Andeobu, L., Wibowo, S., & Grandhi, S. (2022). Medical Waste from COVID-19 Pandemic—A Systematic Review of Management and Environmental Impacts in Australia. International Journal of Environmental Research and Public Health, 19(3), 1381. https://doi.org/10.3390/ijerph19031381
AS/NZS 4187:2014 Reprocessing of reusable medical devices in heal. (n.d.). Retrieved 21 June 2022, from https://infostore.saiglobal.com/en-au/standards/as-nzs-4187-2014-111440_saig_as_as_233112/

Australian Bureau of Statistics. (2021). Patient Experiences in Australia: Summary of Findings. https://www.abs.gov.au/statistics/health/health-services/patient-experiences-australia-summary-findings/latest-release

Babanyara, Y., Garba, T., & Ibrahim, D. (2013). Poor Medical Waste Management (MWM) Practices and Its Risks to Human Health and the Environment: A Literature Review. 7(11), 9.

Blenkharn, J. I., & Odd, C. (2008). Sharps Injuries in Healthcare Waste Handlers. The Annals of Occupational Hygiene, 52(4), 281–286. https://doi.org/10.1093/annhyg/men010

Borusiak, B., & Kucharska, B. (2019). Sustainability in Retailing: A Study of Consumer Intentions Regarding Involvement in Charity Shop Activities. Studia Periegetica, 21.
Branch;, c=AU; o=The S. of Q. ou=Queensland H. ou=; ou=Communicable D. (n.d.). Cleaning and disinfecting shared patient care equipment [Text]. corporateName=The State of Queensland; jurisdiction=Queensland. Retrieved 23 March 2022, from https://www.health.qld.gov.au/clinical-practice/guidelines-procedures/diseases-infection/infection-prevention/standard-precautions/cleaning-disinfecting

Brisbane City Council. (2022, February 18). Recycling guide for households [Text]. https://www.brisbane.qld.gov.au/clean-and-green/rubbish-tips-and-bins/reducing-waste-at-home/recycling-guide-for-households

Canadian Society of Gastroenterology Nurses & Associates. (2014, March 6). Use of Reusable Medical Devices in Endoscopy Settings. Canadian Society of Gastroenterology Nurses and Associates. https://web.archive.org/web/20140306204328/https://csgna.com/en/guidelines/reusable.html

Chartier, Y., Emmanuel, J., Pieper, U., World Health Organization, Prüss-Üstün, A., Rushbrook, P., & Stringer, R. (2014). Safe Management of Wastes from Health-care Activities: A Practical Guide. World Health Organization. http://ebookcentral.proquest.com/lib/qut/detail.action?docID=1771388

Choi, B. C. K., & Pak, A. W. P. (2004). A Catalog of Biases in Questionnaires. Preventing Chronic Disease, 2(1), A13.

Chun Tie, Y., Birks, M., & Francis, K. (2019). Grounded theory research: A design framework for novice researchers. SAGE Open Medicine, 7, 205031211882292. https://doi.org/10.1177/2050312118822927

Clinical waste—A major environmental burden. (n.d.). Retrieved 15 April 2022, from https://www.hospitalhealth.com.au/content/design-in-health/article/, http://hospitalhealth.com.au/content/design-in-health/article/clinical-waste-a-major-environmental-burden-53426063

Cohoon, B. D. (2002). Reprocessing Single-use Medical Devices. AORN Journal, 75(3), 557–567. https://doi.org/10.1016/S0001-2092(06)61177-0

Duane, B., Ramasubbu, D., Harford, S., Steinbach, I., Swan, J., Croasdale, K., & Stancliffe, R. (2019). Environmental sustainability and waste within the dental practice. British Dental Journal, 226(8), 611–618. https://doi.org/10.1038/s41415-019-0194-x

Goldberg, M. E., Vekeman, D., Torjman, M. C., Seltzer, J. L., & Kynes, T. (1996). Medical waste in the environment: Do anesthesia personnel have a role to play? Journal of Clinical Anesthesia, 8(6), 475–479. https://doi.org/10.1016/0952-8180(96)00127-4

Hanington, B., & Martin, B. (2012). Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions. Quarto Publishing Group USA. http://ebookcentral.proquest.com/lib/qut/detail.action?docID=3399583

Health, A. G. D. of. (2020, August 31). Managing coronavirus clinical waste [Text]. Australian Government Department of Health; Australian Government Department of Health. https://www.health.gov.au/news/managing-coronavirus-clinical-waste

ISO 17665-1:2006(en), Sterilization of health care products—Moist heat—Part 1: Requirements for the development, validation and routine control of a sterilization process for medical devices. (n.d.). Retrieved 21 June 2022, from https://www.iso.org/obp/ui/#iso:std:iso:17665:-1:ed-1:v1:en

Jacobs, P., & Akpinar, I. (2018). Single-use medical devices: Economic issues. Heart Asia, 10(2), e011034. https://doi.org/10.1136/heartasia-2018-011034

Jones, C. (2020). Searching for the gold in garbage. ANZCA Bulletin, 29(3), 52–53.

Kagoma, Y., Stall, N., Rubinstein, E., & Naudie, D. (2012). People, planet and profits: The case for greening operating rooms. Canadian Medical Association Journal, 184(17), 1905–1911. https://doi.org/10.1503/cmaj.112139

Laustsen, G. (2007). Reduce–Recycle–Reuse: Guidelines for Promoting Perioperative Waste Management. AORN Journal, 85(4), 717–728. https://doi.org/10.1016/S0001-2092(07)60146-X

Lee, C. C., & Huffman, G. L. (1996). Medical waste management/incineration. Journal of Hazardous Materials, 48(1), 1–30. https://doi.org/10.1016/0304-3894(95)00153-0

McGain, F. (2010). Hospital waste. Issues, 92, 37–39.

McGain, F. (2015). Environmental sustainability in hospitals: An exploration within anaesthetic and intensive care settings. http://hdl.handle.net/11343/59540

McGain, F., Story, D., Lim, T., & McAlister, S. (2017). Financial and environmental costs of reusable and single-use anaesthetic equipment. British Journal of Anaesthesia, 118(6), 862–869. https://doi.org/10.1093/bja/aex098

Moultrie, J., Sutcliffe, L., & Maier, A. (2015). Exploratory study of the state of environmentally conscious design in the medical device industry. Journal of Cleaner Production, 108, 363–376. https://doi.org/10.1016/j.jclepro.2015.06.014

Ordway, A., Pitonyak, J. S., & Johnson, K. L. (2020). Durable medical equipment reuse and recycling: Uncovering hidden opportunities for reducing medical waste. Disability and Rehabilitation: Assistive Technology, 15(1), 21–28. https://doi.org/10.1080/17483107.2018.1508516

Popp, W., Rasslan, O., Unahalekhaka, A., Brenner, P., Fischnaller, E., Fathy, M., Goldman, C., & Gillespie, E. (2010). What is the use? An international look at reuse of single-use medical devices. International Journal of Hygiene and Environmental Health, 213(4), 302–307. https://doi.org/10.1016/j.ijheh.2010.04.003

Priorclave. (n.d.). Autoclave Prices: Industrial Autoclave Pricing. Priorclave - International (En). Retrieved 17 April 2022, from https://www.priorclave.com/en/autoclaves/autoclave-prices/
Prüss-Üstün, A., Rapiti, E., & Hutin, Y. (2005). Estimation of the global burden of disease attributable to contaminated sharps injuries among health-care workers. American Journal of Industrial Medicine, 48(6), 482–490. https://doi.org/10.1002/ajim.20230

Queensland Government. (2018, October 2). Plastic bag ban | Waste reduction initiatives [Collection]. The State of Queensland; corporateName=The State of Queensland; jurisdiction=Queensland. https://www.qld.gov.au/environment/pollution/management/waste/recovery/reduction/plastic-bags

RACGP. (2014). Infection prevention and control standards: For general practices and other office-based and community-based practices (5th edition). The Royal Australian College of General Practitioners.

RACGP - What is General Practice? (n.d.). Retrieved 11 April 2022, from https://www.racgp.org.au/education/students/a-career-in-general-practice/what-is-general-practice

Rutala, W. A., Weber, D. J., & HICPAC. (2008). Guideline for Disinfection and Sterilization in Healthcare Facilities. 163.

Schein, H. (n.d.). Mocom B Classic Autoclave. Henry Schein Equipment Australia. Retrieved 17 April 2022, from https://henryscheinequipment.com.au/sterilisation/mocom-b-classic/

Shwetmala, K., Arkalgud, R., & Anilkumar, M. (2021). A roadmap for bio-medical waste management research. The International Journal of Health Planning and Management, 36(4), 1251–1259. https://doi.org/10.1002/hpm.3170

Standards Australia (Organization), S. N. Z. (2006). Office-based health care facilities: Reprocessing of reusable medical and surgical instruments and equipment, and maintenance of the associated environment. Standards Australia ; Standards New Zealand.
Tao, G. (2012). Design of a Low-cost Autoclave for Adoption in Rural Health Posts of the Developing World. 75.

Terzon, E. (2021, October 12). Healthcare workers are 'dressed in oil' during COVID. They want something to be done about it. ABC News. https://www.abc.net.au/news/2021-10-13/healthcare-waste-covid-plastic-recycling-reusing-hospitals/100533552

Tietjen, L., Bossemeyer, D., & McIntosh, N. (2003). Infection prevention: Guidelines for healthcare facilities with limited resources. JHPIEGO Corp.

Treasure, E. T., & Treasure, P. (1997). An investigation of the disposal of hazardous wastes from New Zealand dental practices. Community Dentistry and Oral Epidemiology, 25(4), 328–331. https://doi.org/10.1111/j.1600-0528.1997.tb00948.x

UNFCCC. (n.d.). Global Warming Potentials (IPCC Second Assessment Report). United Nations Framework Convention on Climate Change. Retrieved 17 April 2022, from https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

Windfeld, E. S., & Brooks, M. S.-L. (2015). Medical waste management – A review. Journal of Environmental Management, 163, 98–108. https://doi.org/10.1016/j.jenvman.2015.08.013

Wyssusek, K. H., Keys, M. T., & van Zundert, A. A. J. (2019). Operating room greening initiatives – the old, the new, and the way forward: A narrative review. Waste Management & Research, 37(1), 3–19. https://doi.org/10.1177/0734242X18793937

Wyssusek, K., Keys, M., Laycock, B., Avudainayagam, A., Pun, K., Hansrajh, S., & van Zundert, A. (2020). The volume of recyclable polyethylene terephthalate plastic in operating rooms – A one-month prospective audit. The American Journal of Surgery, 220(4), 853–855. https://doi.org/10.1016/j.amjsurg.2020.05.011

Zuberi, D. (2013). Cleaning Up: How Hospital Outsourcing Is Hurting Workers and Endangering Patients. Cornell University Press. https://doi.org/10.7591/cornell/9780801450723.001.0001

APPENDIX 1: INTERVIEW QUESTIONS

ID	Type of Question	Question	Area of Interest
1	Statement	Thank you for aggreeing to meet with me today. The thesis I am doing with QUT is investigating the question, how can health professionals remain economically, socially and environmentally sustainable while reducing medical waste disposal in their practice? Today we will be going through several quantitative and qualitative questions covering asepts of the medical waste mangement practice. It is expected to take roughly 30 minutes, howevever we are free to go a bit longer if you feel comfortable. Feel free to stop me at any time throughout the interview. A reminder that this interview will be recorded and later transcribed for future thematic analysis. Any Questions before we begin?	Meta
2	Quantitative	What is your role? Where do you work? (department/Clinic) How long have you been there?	Individual
3	Quantitative	What types of medical waste is being generated in your practice?	Department
4	Quantitative	On a typical day, how often are you generating medical waste?	Individual
5	Quantitative	What existing processes are in place to effectively dispose of medical waste?	Department
6	Quantitative	How much would you say of the medical waste disposed of is reused or recycled?	Department
7	Quantitative	How is each waste stream segregated in your department/practice?	Department
8	Qualitative	What does sustainability mean to you in your practice?	Individual
9	Qualitative	1. What factors drive your current waste management practices?	Individual
10	Qualitative	2. What about these processes helps or hinder you?	Individual
11	Qualitative	3. How effective do you believe these processes are at reducing your environmental impact?	Individual/Department
12	Qualitative	1. If there are any, what opportunities do you see that could improve the sustainability of your waste management practices?	Department
13	Qualitative	2. What roadblocks do you see preventing these opportunities from being implemented?	Department
14	Qualitative	3. In your personal opinion do you feel that your practice produces unnecessary medical waste? Tell me what you think about that?	Individual
15	Qualitative	How do you try to minimize your own medical waste?	Individual
16	Qualitative	Is there anything else you would like to add about medical waste or sustainability that we haven't discussed?	Meta
17	Statement	Okay, that brings us to the end of our interview. I would like to thank you for the time you have made for me. I will now stop the recording.	Meta

APPENDIX

APPENDIX 2: CODING

Theme	Group	Code	Density	Description
Economic	**Administrative Influences on Wa**	Availability	3	Examples of availability of things causing an excess of waste.
		Initiatives	9	Examples of initiatives that take place in the interviewees workplace that has a direct affect on waste.
		Liability	8	Concerns regarding liability of action taken within a medical practice.
		Memo	3	Corporate communction. Typically from management telling staff something related to waste practices.
		Policy & Regulation	23	Examples of policy and regulation that influences how waste is generated or disposed of in a medical prac
	Influences on Waste Production	Being Prepared	10	Waste being generated as a result of needing to be prepared for a procedure but not necessarily using all
		Case-by-Case	20	Dependent on a partiuclar situation or need based on procedure
		Cost	36	Cost of an indiviudal item is what influences what is bought and what is not.
		Infection Risk	8	Infection risk influceing the need to generate more waste as a result of sterilization.
		Standardisation	17	Things be standardised are why certain types of waste are being perpetuated.
		Sterilization	27	Related to action of sterilization of something
		Time	17	Influences of waste as a result of a time poor individuals.
		Volume	8	Large amount of something
	Types of Waste	Biohazard	15	Examples of biohazerdous waste
		Consistent Waste	9	Examples of regular sources of waste as a result of medical.
		Device	17	Examples of equipment waste
		Metalware	13	Examples of metalware waste, typically of a result of being single use only.
		Necessary Waste	17	Waste necessary from any form of treament.
		Packaging	14	Examples of packaging waste.
		Paper	28	Examples of Paper waste
		Plastic	44	Examples of Plastic Waste
		PPE	32	Examples of PPE waste
		Procedure Pack	16	Examples of a kit usage and waste
		Sterilization Fluid	5	Ampoules of sterilization fluid found in cabinet from the cultural probe.
		Sterilization Wipes	8	Sterilization wipes found in a storage cabinet from the cultural probe.
Environmental	**Categories of Devices**	Reusable	9	Resuable after a use
		Single-use	41	Thrown out after a single use. Whether for infection control, sterility or manufacture says so.
	Environmental	Environment	11	Quotes regarding the envrionment by the interiviewee.
	Waste Methods	Disposal	28	Action of disposing
		Incinerate	3	Examples of incenirations when disposing of waste.
		Recycle	17	References to recyling, typically packaging waste.
		Sharps	28	Examples of sharps disposal
		Spatial Placement	4	Placement of typically a bin.
		Third-Party Interventio	8	Waste externally handeld by paid services
		Waste Reduction	19	Oppourunties identified by interviewees where waste could be reduced.
		Waste Segregation	29	Examples of actions of waste segregation.
Social	**Forms of Unnecessary Waste**	Duplication	5	Duplication, typically of tests, influcening waste creation. Typically as a result of communictaion failure.
		Excess	18	Excess in processes and procedures as a result of needing to be prepared.
		Uncertantity	9	Uncerntantiy about waste or a health outcome leading to more waste.
	Impacts of Healthcare	Infection Control	15	Discussion about actions or thoughts related to infection control.
		Patient Care	29	Action or discussion relating to patient care in the medical setting.
		Priority on Health	11	Action or discussion displaying a priority on health
		Staff Saftey	18	Action or discussion relating to staff saftey in the medical setting.
	Social Behaviours & Emotions	Apathy with waste	5	Lack of concern for what waste they might produce.
		Busy Behaviour	11	Busy and active situations will typically lead to poorer waste practies.
		Caution Behaviour	18	Caution from the indivudal influencing waste practices, typically generating more.
		Collaboration	9	Colloboration as a method of reducing waste.
		Comfort	6	Concern for the comfort of their patients.
		Communication	11	Methods of communction.
		Complacent	4	Complacent in their current practcies and may not have any desire to change.
		Demand	3	External demands on practioniners or clinics
		Effort	3	Effort beign made to “go the extra mile” to be more sustainable in their practice.
		Fatigue	3	Things failing to happen sometimes because they are fatigued.
		Frustration	5	Frustration from the interviewee regarding the state of the waste process in their practice.
		Inconvientent	7	Inconvientent location of something leading in to frustration
		Personal Belief	2	Displaying personal beliefs towards medicine or the environment.
		Stigma	2	The stigmas associated with the patients perception of a health related thing.
	Waste Reduction	Consumer Demand	5	Discussions about consumer demand promoting change, resulting in reduction of waste.
		Oppourtunity	9	Examples of oppoutuntites highlighted by the participant to reduce waste.
		Technology	10	Example of technology discussed being used to reduce waste.
		Training	10	Examples of training discussed resulting in reduced waste.

APPENDIX 3: LEADERSHIP

As a portion of this project, I took on external collaborations with industry partners to better my leadership skills and establish myself as a competent designer in Brisbane. I have attended several events hosted by the DIA over the years, including an online discussion with industry leaders in June of 2020. Artichoke Night School event at the Living Edge, with a panel of design duos, from Flack Studio, Blacklash Creative and Kin Architects (Figure 1).

Figure 1. Artichoke Night School. Design Duos

Lastly, a DIA community event discussing IP at Street Garden in June 2022, where we had an open discussion on IP protections, design registrations and copyright (Figure 2). For this event, we benefited from an IP lawyer, Nicole Murdoch from Eagle Gate Lawyers, offering deep insight into the process. I had found this session at Street Garden extremely valuable as topics like IP are often omitted from my studies at QUT. The event also afforded interactions with industry leaders such as David Shaw and Robert Geddes. They were open and willing to talk about everything design. They offered great insight into their relationship with design and IP. Some of which I have been able to apply to my own practice, especially when completing New Product Development, which had centred on the business component of design.

Figure 2. DIA event at Street Gardern on IP