USABILITY TESTING OF A U-500 INSULIN SYRINGE:
A Human Factors Approach

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Currently, 8.3% of the population, 25.8 million people, has diabetes in the United States. Not all of those 25.8 million have been diagnosed as diabetics. Among patients with diabetes, 90% to 95% are diagnosed with type 2 diabetes, which often requires treatment with insulin (CDC, 2010).

Injectable insulin is typically prescribed as a U-100 dose for diabetic patients. Those patients developing resistance to U-100 insulin typically require U-500 insulin, which is fivefold stronger in concentration. However, the manufacturer of U-500 insulin does not provide an exclusive syringe for the delivery of this concentrated drug. As a result, industry leaders have recommended a tuberculin syringe be utilized to deliver the concentrated form of insulin. This is a less than optimal solution because this delivery system is not specifically designed for this purpose. A prototype syringe, designed exclusively for the delivery of U-500 insulin, is being proposed by a manufacturer.

Nationally, confusion between U-100 and U-500 insulin concentration during prescribing, dispensing, and administrating has caused significant patient morbidity and mortality. If insulin is underdosed, hyperglycemia may develop leading to blurred vision, unconsciousness, fatigue, shortness of breath, and diabetic ketoacidosis (National Diabetes Information Clearinghouse, 2012). If insulin is overdosed, acute hypoglycemia may occur.

The Institute for Safe Medication Practices (ISMP) has recommended "consistent use of a tuberculin syringe with U-500 insulin, with total doses expressed in terms of both units and volume i.e. 200 units (0.4mL)." The United States Department of Veterans Affairs National Center for Patient Safety (NCPS) reviewed the Patient Safety Information System called SPOT, a database created by NCPS, and found multiple patient incidents related to U-500 insulin.

ISMP and the NCPS have found significant risk in not having a specific syringe for the administration of concentrated insulin:

> *588 VHA patients received U-500 insulin during Q4FY08, of these patients, 124 had a concurrent Rx for NPH, insulin glargine or insulin detemir. As of 2011, 805 VHA patients received U-500 insulin. (Yinong Young-Xu personal communication July 18, 2012)*

NCPS issued Patient Safety Alert AL09-15 on March 3, 2009, titled "Medication Safety- Insulin U-500 Safety Enhancements" (National Center for Patient Safety, 2009).

Although tuberculin syringes are a more acceptable alternative than the U-100 syringes, a customized U-500 syringe clearly stating the intended use with U-500 insulin providing volume marking in milliliters (mLs) and dose, in addition to improvements delineated in the recommendations, would be a better option. As a result of these safety concerns and the Patient Safety Alert, a medical device manufacturer designed a syringe specifically designed to be used with U-500 insulin. (see Figure 1)

The purpose of our study was to conduct a human factors and usability study on the prototype U-500 syringe to reveal the strengths and limitations of this device specifically when used with U-500 insulin.

METHODS

The primary goal of this human factors and usability test was to determine the unintended consequences of introducing a new, specifically designed, U-500 syringe to the market. The evaluation was designed to observe and analyze the intuitive selection of the correct syringe for a corre-

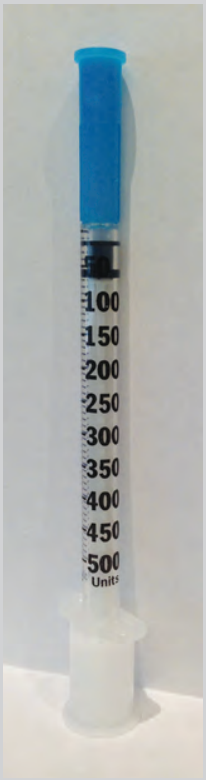

Figure 1: Prototype U-500 Insulin Syringe

sponding dose; applicable volume; ease of use; level of satisfaction and dissatisfaction; user comments, recommendations, and suggestions for improvement.

Recruitment

Recruitment was designed to keep the researchers blind to participants' personal identification and health information. Three subject groups were recruited based on self-reported experience with syringe use: inexperienced (beginner and no experience), intermediate, and expert.

Recruitment letters were drafted for patients and clinicians. Subjects were asked to answer three questions to gauge their syringe experience level as determined by the research team. Patients with experience were placed into Group B, and those who were inexperienced were placed into Group C. Clinicians were all assumed to be at an expert level, and were placed into Group A. Recruitment letters were distributed in high traffic areas of a medical center to attract attention from both patients and clinicians.

Questionnaire and Training

Participants completed a questionnaire to gather demographic information (age, gender, medical training, and experience in syringe use). Participants indicated their level of experience. However, to improve study reliability, the research team confirmed the accuracy of participant placement without compromising identification.

Inexperienced participants (Group C) were required to undergo "just-in-time" training; a short PowerPoint presentation developed by the research team on the basic use of generic syringes with neutral colors so that participants would not make inferences based on what was shown. Users were made aware that this training should not be used in place of formal medical guidance or instruction as it was solely for the purpose of this study.

Study Design

Subjects were asked to select the correct syringe among two syringe choices, a U-500 (Figure 1) and a U-100 syringe (Figure 2), when faced with three different dosing situations.

Subjects were asked to draw up the correct amount of fluid (water) that was indicated on the randomly selected dose card. Dose cards were consistently arranged so that the first dose was U-500 concentration and less than 100 units. The second dose was U-100 concentration and 100 units or less. The third dose was U-500 concentration and 100 units or higher. All U-500 dose cards indicated units as well as the volume in mLs as recommended by ISMP [e.g. 200 Units (0.4 mLs)].

During this process, the subject was asked to follow think-aloud protocols as they performed the task. Researchers documented the selection of the syringe, the accuracy of the amount of fluid aspirated and verbal feedback. Participants were also asked three oral questions about their observations and were requested to answer 15 written questions regarding syringe ease of use and selection.

Prior to data collection and the study design, it was hypothesized that clinicians (Group A) would have high success rates (0.99). A sample of 32 subjects were needed to detect an alternative success rate of 0.96 or lower in this group (α=0.05, β=0.20).

Data from the 101 subjects was summarized to demonstrate the percent of correct choices. Qualitative data was also analyzed on user suggestions for changes to the U-500 syringe, making it more distinguishable from the U-100 syringe.

RESULTS

Table 1 (page 40) shows the demographic distribution of the participants and the percentage of incorrect and correct syringe choices by participants for the first dose (U-500 insulin less than 100 units), second dose (U-100 insulin less than 100 units) and third dose (U-500 insulin greater than 100 units). The data is further stratified by experience (Groups A, B, and C).

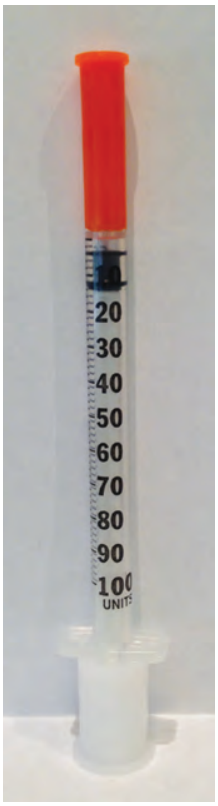

Figure 2: U-100 Insulin Syringe

Although there was a significant difference in the percentage of males and females within the three groups ($p<0.005$), this difference, while interesting, is unlikely to have impacted the results. The data showed no statistically significant difference in age between the three groups ($p<0.177$). By experimental design there was significant difference between the three groups regarding formal healthcare training and syringe use as well as experience ($p<0.001$). There was no significant difference in success rates in all doses by all groups.

After the hands-on experiment, the participants responded to three open-ended questions. Participants were asked if they experienced any trouble in using the device and even though many may have been using the device incorrectly, 63 out of 101 participants (63%) did not perceive that they had any difficulty using the syringe, which is in line with dose 2 and dose 3; perhaps not for dose 1.

Fifteen out of the 101 had difficulty reading the numbers and lettering on the syringe. According to the National Eye Institute, approximately 40% to 45% of Americans diagnosed with diabetes have some stage of diabetic retinopathy (National Eye Institute, 2012). Besides diabetic retinopathy, diabetic patients are prone to developing cataracts and glaucoma, impacting their ability to read small print.

Afterward, the participants were asked if they noticed any difference between the U-100 and the U-500 syringes while they had performed the hands on exercise. The participants were not given the opportunity to inspect the syringes during this ques-

Table 1. Demographic distribution and experimental results

Characteristics		Group A	Group B	Group C	Total	p-value*
Gender	Male	11 (34%)	23 (72%)	24 (65%)	58 (57%)	
	Female	21 (65%)	9 (28%)	13 (35%)	43 (43%)	<0.005
Age	18-20	0	3 (9%)	2 (5%)	5 (5%)	
	25-34	3 (9%)	3 (9%)	5 (13%)	11 (11%)	
	35-44	7 (22%)	0	3 (8%)	10 (10%)	
	45-54	9 (28%)	10 (32%)	15 (41%)	34 (33%)	
	55-64	11 (35%)	13 (41%)	9 (24%)	33 (33%)	
	65+	2 (6%)	3 (9%)	3 (8%)	8 (8%)	0.177
Formal Health Care Training	Yes	32 (100%)	13 (41%)	4 (11%)	50 (49%)	
	No	0	19 (59%)	32 (87%)	50 (50%)	
	Unknown	0	0	1 (2%)	1 (1%)	<0.001
Experience	None	1 (3%)	0	32 (86%)	33 (33%)	
	Beginner	3 (9%)	13 (41%)	4 (11%)	20 (20%)	
	Intermediate	6 (19%)	16 (50%)	1 (3%)	23 (23%)	
	Expert	22 (69%)	3 (9%)	0	25 (25%)	<0.001
Dose 1 Performance	Correct	17 (53%)	10 (31%)	20 (54%)	47 (47%)	
	Incorrect	15 (47%)	22 (69%)	17 (46%)	53 (53%)	0.111
Dose 2 Performance	Correct	28 (88%)	28 (88%)	34 (92%)	89 (89%)	
	Incorrect	4 (13%)	4 (13%)	3 (8%)	11 (11%)	0.784
Dose 3 Performance	Correct	31 (97%)	27 (84%)	30 (81%)	88 (87%)	
	Incorrect	1 (3%)	5 (16%)	7 (19%)	13 (13%)	0.103

*p-values measure whether each of the characteristics are significantly different across the three subject groups using Chi-square (or Fishers' Exact when expected cell count < 5).

tion. The numerical units on volume as well as the maximum dose were noticed by 31 out of 101 (31%). Seven out of 101 participants noticed only a color difference between the syringes (7%). The syringe color and units were noticed by 53 out of 101 participants (53%). Differences between the syringes were not noticed at all by 13 out of 101 participants (12%).

Participants were asked to respond to this open-ended question: *"Is there a routine you would use every time you need to inject insulin to ensure you did not accidently grab the wrong syringe?"*

Responses included:

Don't have both kinds of syringes in the house.
Keep the correct syringe with the correct vial.
Color match the syringe with the vial.
Tape the correct syringe to the correct vial.
Keep the drug and syringe in a separate compartment of the travel bag.

Similar ideas to improve the process were voiced by multiple participants:

"The syringe and vial should be kept together" was made by 31 out of 101 participants (31%).
"Insulin vial and syringe should color match" was made by 14 out of 101 participants (14%).
"The insulin and the syringe should be packaged together" stated by 3 out of 101 (3%).
"If both U-100 and U-500 syringes and insulin were present in a household, the medication and corresponding syringes should be kept away from each other" was stated by 32 out of 101 participants (32%).

After participants responded to the open-ended questions, a series of Yes/No usability questions were asked. Table 2 shows the distribution of the participants' responses.

Table 2. Distribution of participants' responses to Yes/No usability questions

		Yes	No
Labeling	Are you able to tell the difference between syringes based on the unit amounts	92%	7%
	Is the labeling confusing in any way?	40%	59%
	Are you able to tell the difference between syringes based on the "U-100" or "U-500" printed on the barrel?	80%	19%
	Are the labels readable?	84%	15%
	Are the labels smudged or blurry?	17%	82%
Cap Color	Are you able to tell the difference between syringes based on the color of the cap covering the tip end?	87%	12%
	Is there a big enough difference between the blue and orange colors?	86%	13%
Tip End Cap Shape	Can you tell the difference between syringes based on the shape of the cap covering the tip end?	21%	78%
	Is there a large enough difference between the two syringes in the way the cap feels based on shape and texture?	15%	84%
Plunger Cap Shape	Can you tell the difference between syringes based on the shape of the cap covering the plunger?	11%	87%
	Is there a large enough difference between the two syringes in the way the plunger cap feels based on shape and texture?	8%	91%
Plunger Shape	Can you tell the difference between syringes based on the shape of the plunger?	9%	90%
	Is there a large enough difference between the two syringes in the way the plunger feels based on shape and texture?	8%	91%
Shape/Size of the Barrel	Are you able to tell the difference between syringes based on the shape or size of the syringe barrel?	17%	83%
	Is there a large enough difference in the tactility (the feel) of the barrel shape between syringes?	8%	90%

Participants ranked 9 factors/features of syringe design (most helpful first and the least helpful last) to assist in distinguishing between the 2 syringes. Numbers in parenthesis indicate the frequency counts.

LIST OF KEY POINTS

- *There have been adverse events related to the administration of concentrated insulin.*
- *Currently, there is no specific device for the administration of U-500 insulin.*
- *Now that a prototype U-500 insulin syringe is being designed, there is a need for usability testing to ensure the safe use of the device.*
- *More than 100 participants were recruited and given a series of tasks and questionnaires.*
- *Findings were unanticipated and revealed room for improvement of the device.*
- *There will be consequences for design and clinical use of this syringe.*
- *Recommendations alongside education and cognitive aids are to label syringe with distinct, large font and prepackage syringe with corresponding drug.*

1. Labeling size (355)
2. Tip end cap color (362)
3. Labeling color (376)
4. Labeling dosages (382)
5. Plunger cap color (417)
6. Tip end cap shape (450)
7. Size of barrel (460)
8. Shape of barrel (461)
9. Plunger cap shape (491)

DISCUSSION AND RECOMMENDATIONS

The most striking finding from this study was the percentage of incorrect syringe selection for Dose 1 (U-500 insulin less than 100 units) by all groups, particularly by Group A experts. Clinicians chose the incorrect syringe 47% of the time, which is almost the same as the average of all three groups (53%).

One possible explanation is that clinicians are trained to use the most accurate measurement tool for the task at hand. Clinicians, like many scientists, are taught and trained to use a measuring device that would provide optimum accuracy. More than one participant in Group A stated, "I will use the smaller syringe because the gradations are smaller therefore it will be more accurate."

For example: in order to deliver 0.75 mL of saline, if given the choice, a majority of clinicians use a 1 ml pipette instead of a 5 ml or a 10 ml pipette to draw up the saline. When the U-500 insulin dosages were below 100 Units the majority of clinicians chose a U-100 syringe instead of the U-500 syringe. In such a case, the patient would receive five times the intended U-500 insulin dose. Likewise, clinicians have a tendency to use a U-100 syringe instead of a U-500 syringe if the dose is less than 100 units regardless of the concentration.

It is interesting to note that Group C, those with little or no experience, did better than the other two groups in the first two doses. This might be due to the "just-in-time" training and the unfamiliarity of the device, which may have led participants to proceed with greater caution and attentiveness.

The results indicated that even those with formal medical training were prone to making mistakes with the U-500 syringe. Participants provided feedback on which improvements would make choosing the correct syringe easier. Many participants voiced concerns that the U-100 syringe and U-500 syringe, outside of color, were too similar and needed more differentiation.

It can be inferred from the data that the most beneficial alterations would be ones made to the size (355), shape (450), tactility, and labeling (376) of the syringe. Since the tip end cap color (362) was rated as one of the most helpful features to distinguish between the syringes, we recommend a striped, colored, end cap with U-500, in large font, printed in two places, 180 degrees apart. Labeling size (355) and labeling color (376) were the next two features rated as most helpful.

The research team recommends increasing the font size of the label U-500 on the barrel of the syringe and changing the color of the plunger gasket to match the striped tip end cap color, or changing the color of the gradations and the text on the barrel of the syringe. Color matching the syringe with the vial of insulin was also highly recommended by the participants. Some felt that creating a groove or indentation of the U-500 syringe would help those with vision issues to identify the device via touch. Many believed that a size difference in the length and/or width of the barrel between the U-500 syringe and U-100 syringe would be of benefit. Participants mentioned that an attachable magnifier could help those who may have issues reading the syringe. Results of the study show there will be implications for use of the U-500 syringe in the current state. Education of ALL diabetic patients who are on injectable insulin therapy is a must although according to the NCPS action rating scale, education is the weakest of the three action ratings. Intermediate actions would include a cognitive aid or a checklist. The strongest action would be to create a forcing function, which means that the correct corresponding syringe is prepackaged with the prescribed concentration of injectable insulin. If the syringe cannot be packaged with U-500 insulin, there needs to a way to prevent the U-100 syringe or any other syringe to access the U-500 insulin vial and the U-500 syringe not access any other medication.

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CONCLUSIONS

This particular study looked at the usability of a new syringe developed to deliver higher concentrations of insulin. A variety of vulnerabilities of the U-500 syringe were discovered. This study did not consider the further implications of letting the device enter the healthcare environment. Further study should address the possible consequences of introducing a new syringe to the wider healthcare environment. In concept, the U-500 syringe is a necessary device for the administration of U-500 insulin, however, it is very clear that modifications are mandatory for the safe and effective use of this device before it is introduced to the market.

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