SUPPLEMENTARY INFORMATION

Urine Osmolality Assessment through the Integration of Urea Hydrolysis and Impedance Measurement

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NOISE-TO-SIGNAL RATIO OPTIMIZATION FOR RESISTANCE MEASUREMENT

We investigated the influence of frequency on the noise-to-signal ratio in impedance measurements for varying NaCl concentrations. To achieve this, a frequency sweep was conducted, ranging from 1 kHz to 1 MHz. At each discrete frequency, the noise-to-signal ratio was determined across a range of NaCl concentrations (0.05 M to 0.5 M). To account for measurement variability, impedance measurements were repeated three times for each frequency-concentration combination. The mean resistance (*R*) and its standard deviation (σ) were subsequently calculated.

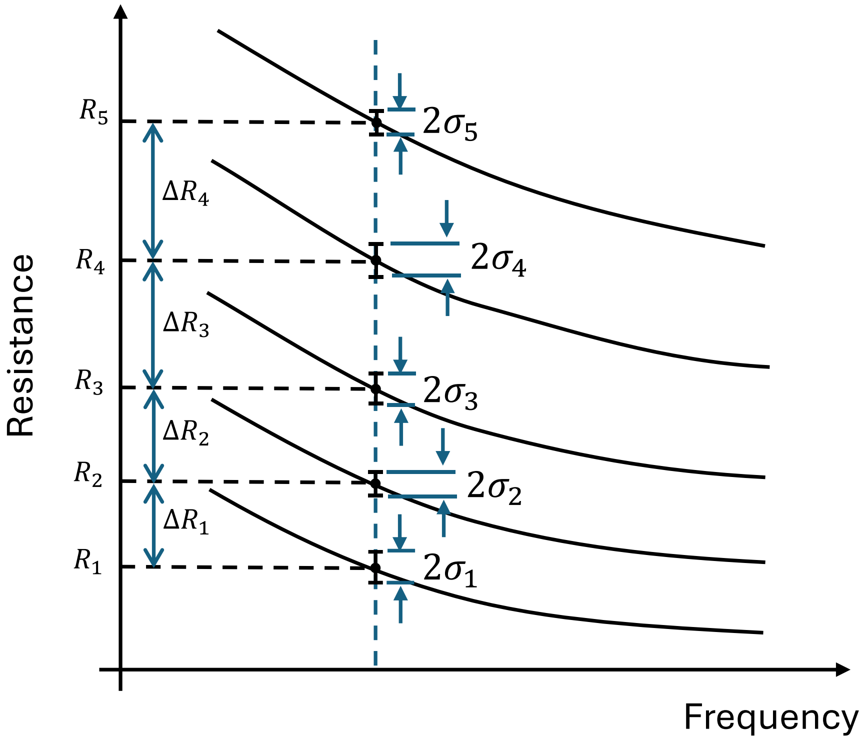

Figure S1: *Schematic diagram for the resistance vs frequency plot. For each frequency-concentration, we repeated the measurements three times to obtain the mean resistance, R and the standard deviation, σ.*

The noise-to-signal ratio, $\sum \sigma/\Delta R$ for each frequency is defined as the summation of ratio between standard deviation and the average resistance gap. The aim is to minimize the error in the sample measurements σ while increasing the gap or separation in the mean resistance.

$$\sum \sigma/\Delta R = \frac{\sigma_1}{\Delta R_1} + \frac{\sigma_2}{(\Delta R_1 + \Delta R_2)/2} + \frac{\sigma_3}{(\Delta R_2 + \Delta R_3)/2} + \frac{\sigma_4}{(\Delta R_3 + \Delta R_4)/2} + \cdots + \frac{\sigma_5}{\Delta R_4}$$

The results of this investigation are depicted in Figure S2 and S4, which illustrates the relationship between noise-to-signal ratio, $\sum \sigma/\Delta R$ and applied frequency.

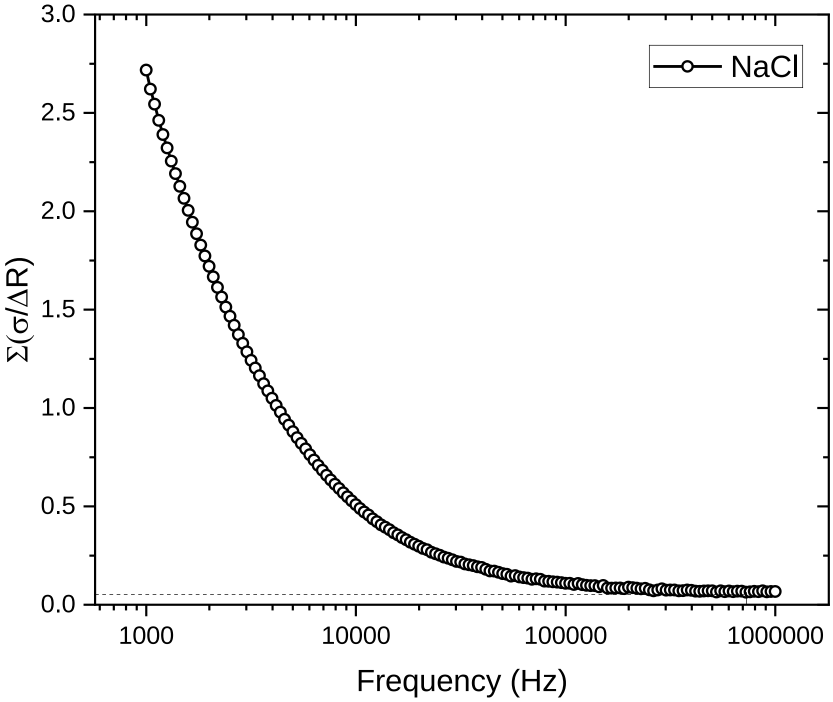

Figure S2*: Plot of noise-to-signal ratio, $\sum \sigma / \Delta R$ and applied frequency for NaCl. The optimal frequency with the lowest noise-to-signal ratio is 724 kHz. Increasing the applied frequency above the optimal frequency yielded no additional benefit.*

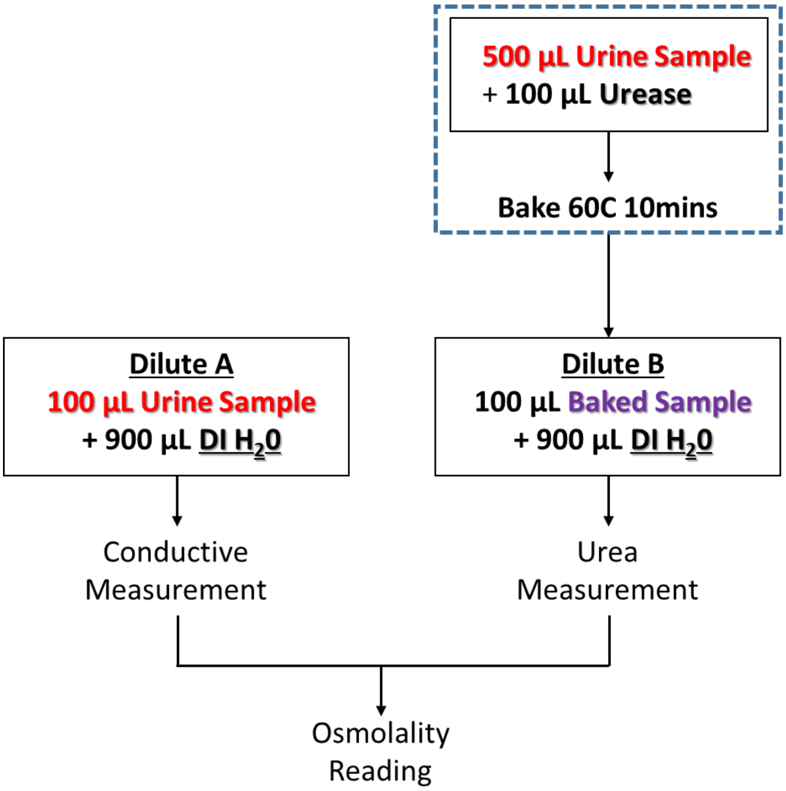

***Figure S3**: Summary of the urine osmolality measurement procedures for first prototype.*

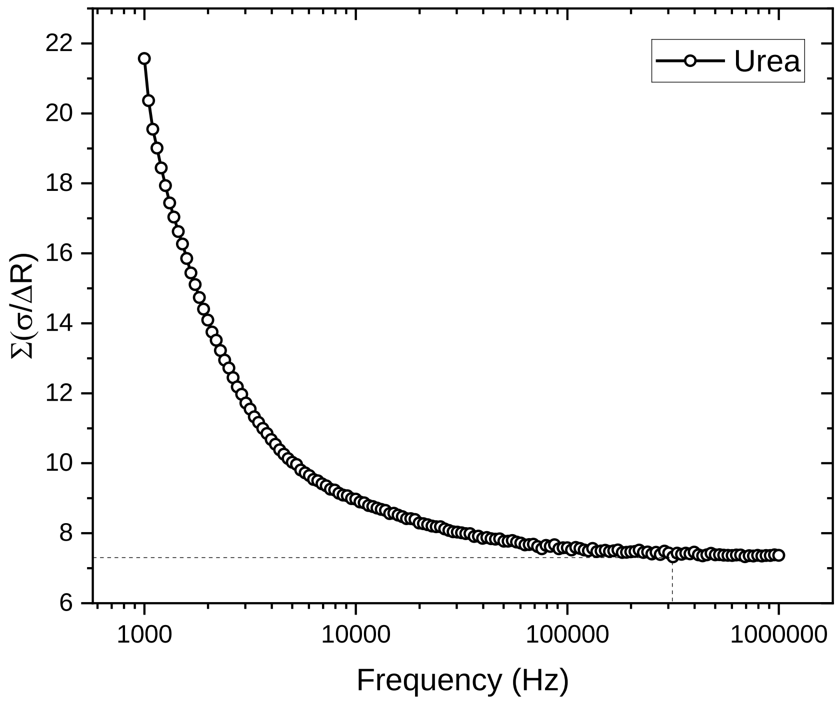

***Figure S4**: Plot of noise-to-signal ratio, $\sum \sigma/\Delta R$ and applied frequency for urea. The optimal frequency with the lowest noise-to-signal ratio is 316 kHz. Increasing the applied frequency above the optimal frequency yielded no additional benefit.*

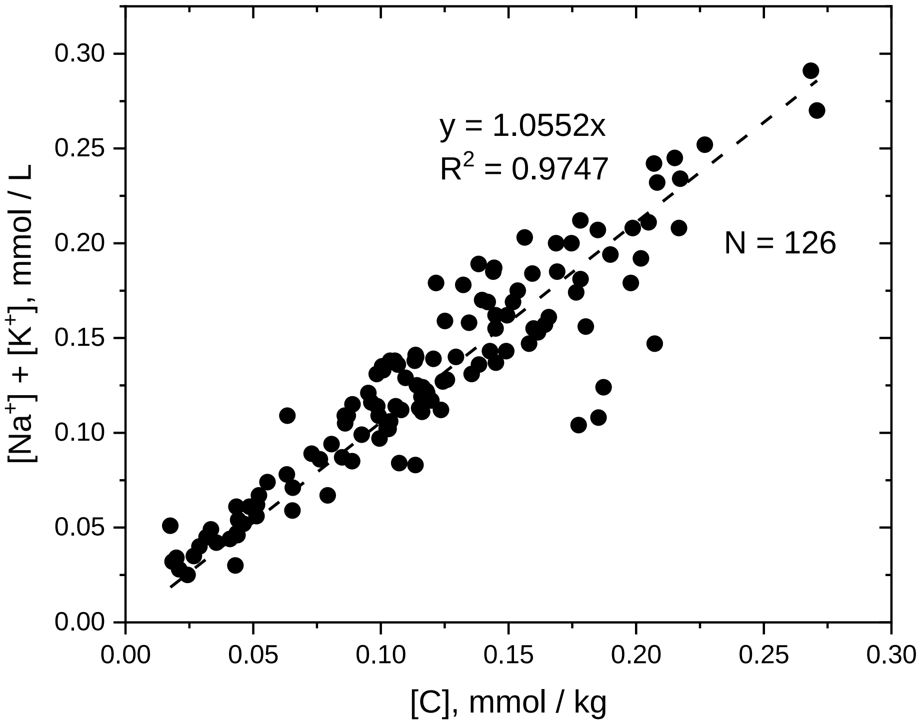

***Figure S5**: Comparison of the conductive concentrations $[C]_{urine}$ (mmol / kg) with the sum of the sodium and potassium ions ($[Na^+] + [K^+]$ mmol / L) of 126 urine samples collected from 31 volunteers.*

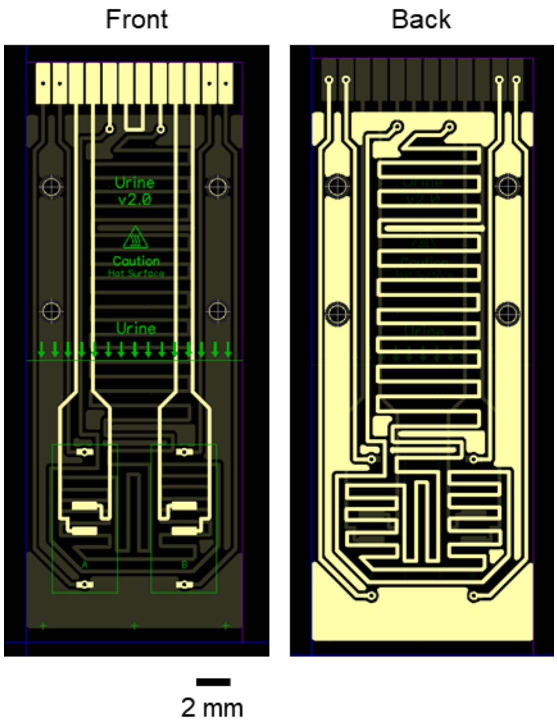

***Figure S6**: Front and back PCB design layout of the urine dipstick. The gap of each pair of the electrode is 2mm.*

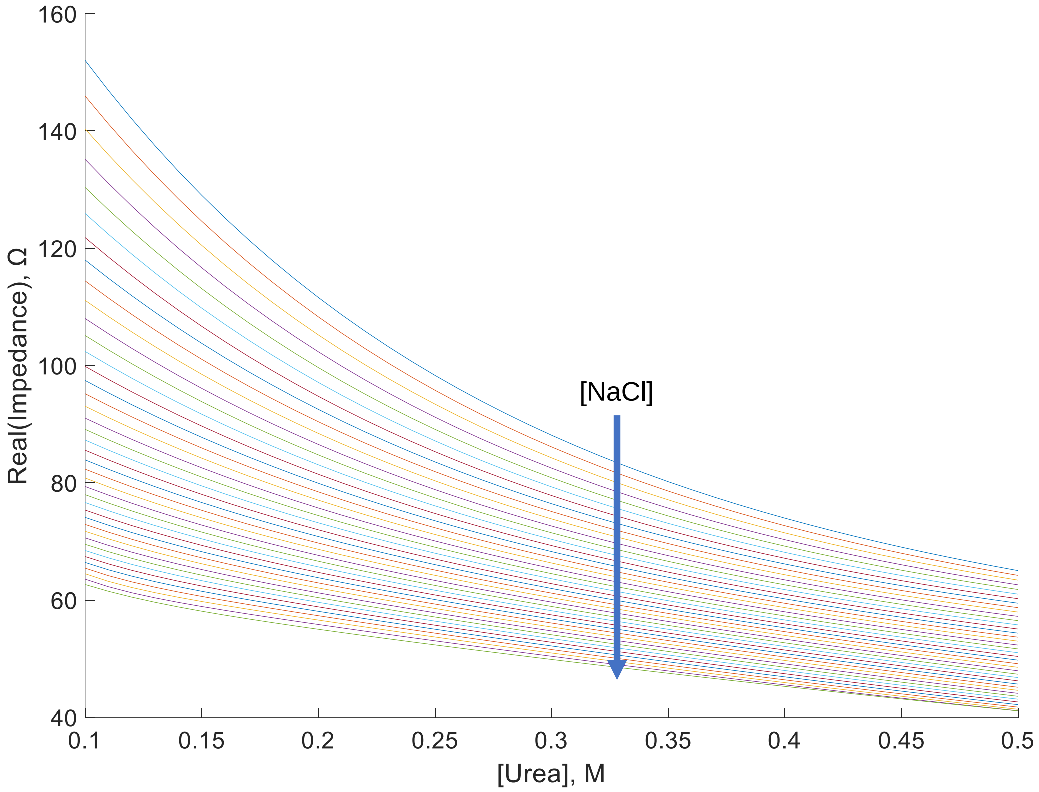

Figure S7: *Discretised and interpolated the resistance – urea curves for various NaCl concentrations at increment of 0.01M.*

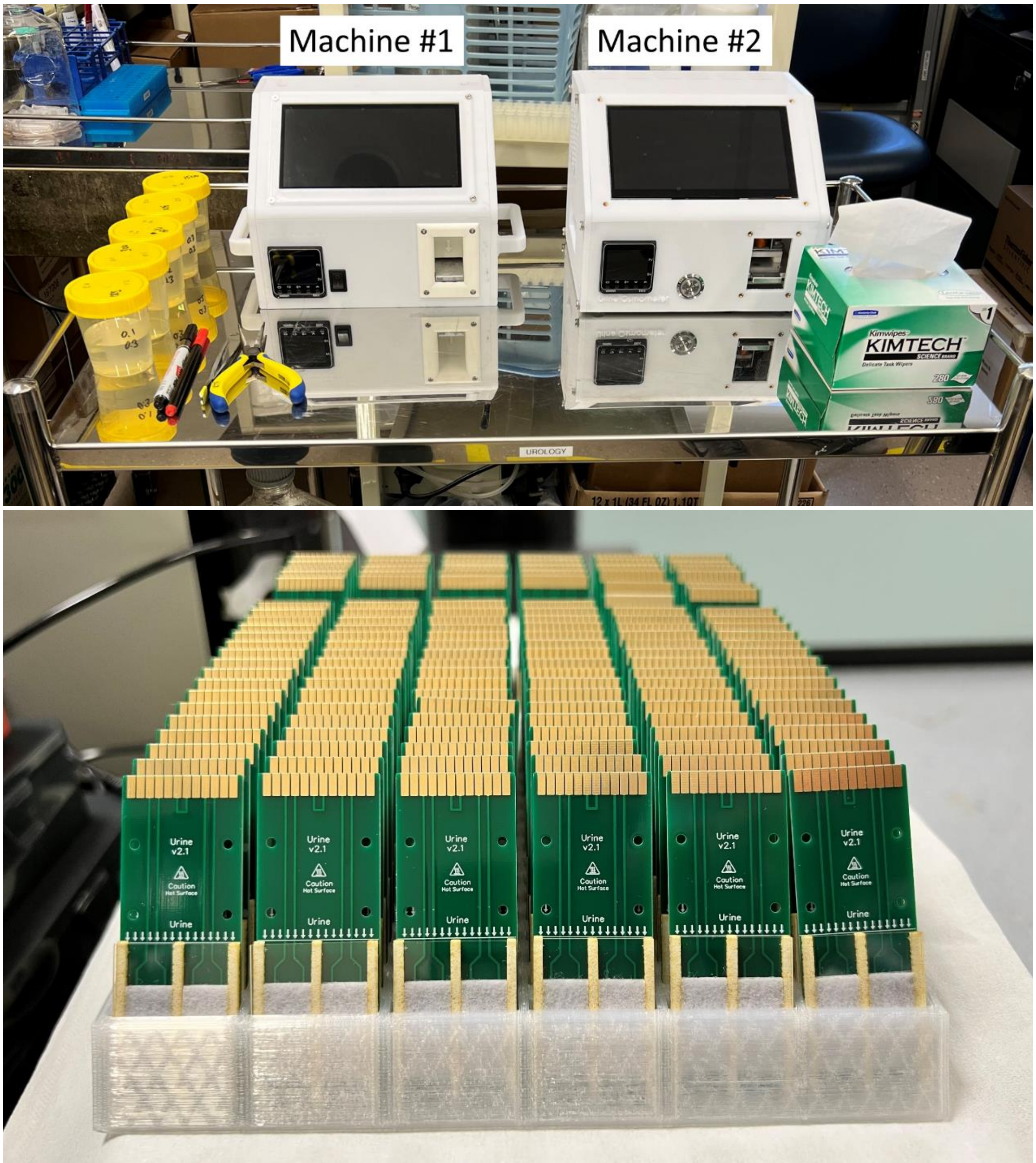

Figure S8: *(Top) Second prototype with integrated urine dipstick reader unit for urine osmolality measurements. The device has impedance analyzer modules and temperature controller. (Bottom) Dipstick for urine osmolality measurement. The dipstick has two compartment – one for conductive measurement, and one is coated with urease enzyme for urea measurement.*

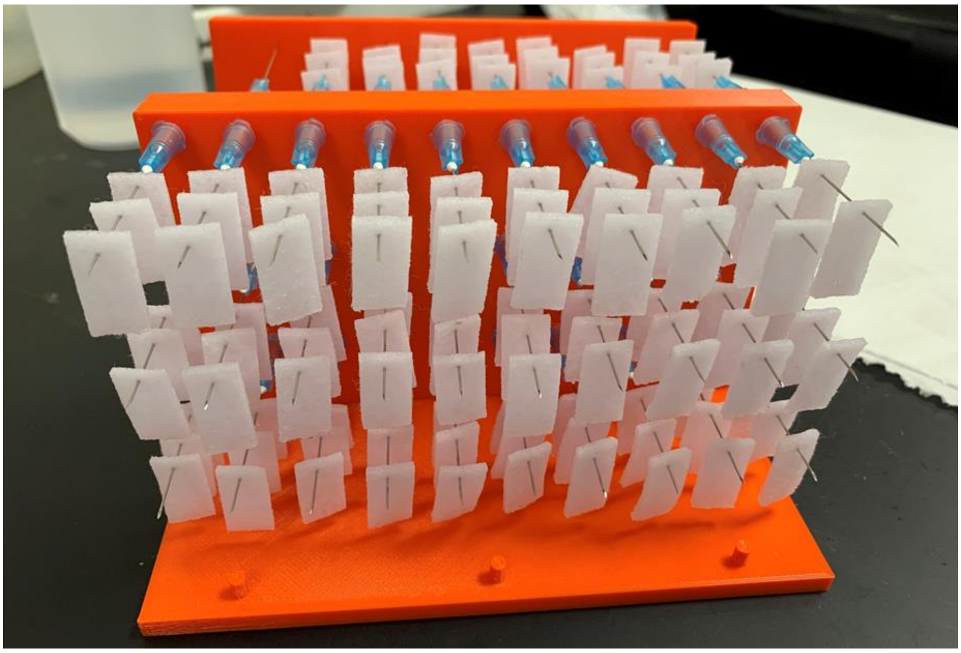

Figure S9: *Coating of enzyme on felt and dried at room temperature.*

Table S1: *Clinical trial results for proof-of-concept first prototype accuracy in comparison to clinical freezing point osmometer readings by SGH laboratory*

#1	Clinical		Prototype			
	NaCl (mM)	**Osmolality (mOsm/kg)**	**Conductive (mM)**	**Urea (mM)**	**Osmolality (mOsm/kg)**	**Accuracy (%)**
6am	59	**262**	81	107	**269**	**97.3**
12pm	125	**552**	136	255	**527**	**95.5**
6pm	72	**484**	126	208	**460**	**95.0**
12am	53	**307**	60	157	**294**	**95.8**
3am	21	**158**	35	87	**155**	**98.1**

#2	Clinical		Prototype			
	NaCl (mM)	**Osmolality (mOsm/kg)**	**Conductive (mM)**	**Urea (mM)**	**Osmolality (mOsm/kg)**	**Accuracy (%)**
6am	49	**269**	81	93	**252**	**93.7**
12pm	52	**180**	71	33	**173**	**96.1**
6pm	90	**458**	127	179	**425**	**92.8**
12am	68	**442**	112	224	**439**	**99.3**
3am	25	**131**	28	62	**117**	**89.3**

#3	Clinical		Prototype			
	NaCl (mM)	**Osmolality (mOsm/kg)**	**Conductive (mM)**	**Urea (mM)**	**Osmolality (mOsm/kg)**	**Accuracy (%)**
6am	83	**431**	99	199	**390**	**90.5**
12pm	142	**688**	206	273	**666**	**96.8**
6pm	87	**485**	161	159	**472**	**97.3**
12am	132	**807**	194	396	**757**	**93.8**
3am	37	**199**	51	83	**183**	**92.0**

#4	Clinical		Prototype			
	NaCl (mM)	**Osmolality (mOsm/kg)**	**Conductive (mM)**	**Urea (mM)**	**Osmolality (mOsm/kg)**	**Accuracy (%)**
6am	148	**694**	186	351	**700**	**99.1**
12pm	77	**316**	116	84	**312**	**98.7**
6pm	230	**795**	290	218	**774**	**97.4**
12am	241	**866**	300	308	**876**	**98.8**
3am	225	**784**	264	289	**791**	**99.1**

#5	Clinical		Prototype			
	NaCl (mM)	Osmolality (mOsm/kg)	Conductive (mM)	Urea (mM)	Osmolality (mOsm/kg)	Accuracy (%)
6am	43	**252**	74	127	**271**	**92.5**
12pm	74	**345**	113	127	**348**	**99.1**
6pm	148	**522**	196	154	**534**	**97.7**
12am	147	**520**	188	134	**500**	**96.2**
3am	63	**285**	86	93	**262**	**91.9**

#6	Clinical		Prototype			
	NaCl (mM)	Osmolality (mOsm/kg)	Conductive (mM)	Urea (mM)	Osmolality (mOsm/kg)	Accuracy (%)
6am	114	**510**	153	209	**504**	**98.8**
12pm	167	**1018**	285	432	**961**	**94.4**
6pm	125	**835**	247	328	**794**	**95.1**
12am	139	**718**	175	328	**658**	**91.6**
3am	85	**708**	158	382	**676**	**95.5**