OR-04 Instruments and tests you can make: thermometer, stethoscope, scale, microscope, blood-pressure cuff, urine tests

HEALING after the FALL, research library, OR-04

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How to read this document

FO-07 gives the examination by hand, eye, ear and nose (THRIVING library, FO-07). This report takes the instruments and bench tests that extend it, one at a time, and asks four questions of each. How close does it come to the reference method? What does it take to make, keep or learn? What is the record of its use where money and power were short? How does it fail? OR-06 lists what the dispensary shelf holds, including five thermometers for a village of 300 (THRIVING library, OR-06). CH-02 covers cuff size and the drift of dials (THRIVING library, CH-02). CH-01 gives the recipe and colour bands for Benedict's test (THRIVING library, CH-01). IN-09 and IN-10 give what the malaria film and the tuberculosis smear mean for treatment (THRIVING library, IN-09, IN-10). The district laboratory bench as a room, with its staff, belongs to OR-07. Where this report touches those subjects it points to them.

Three warnings run through the findings.

- **Accuracy in the paper is accuracy in the best hands.** Nearly every figure below was measured by laboratory staff, often with quality control, against a reference machine. A lay reader after the Fall will do worse, and the gap is largest for the microscope.
- **A test has two errors, and they cost different things.** A false negative sends home a child with malaria. A false positive spends a scarce drug and hides the real cause of the fever. The village must decide which error it fears more for each test.
- **A bad test is worse than none.** A badly stained film, an aged strip or a dial that has drifted gives a number, and a number is believed. The commonest harm in this report is false reassurance.

Chemistry appears at the level of what each test is, what it needs and how accurate it is. Recipes for stains and reagents are not given, apart from what CH-01 already holds.

Findings by section

1. Temperature: the hand and the glass

The tradition. A mother's hand on the forehead is the oldest thermometer and the one every household holds. Carl Wunderlich, in Leipzig, published his study of temperature in disease in 1868. He is reported to have taken over a million readings from about 25,000 people, set the normal mean at 37°C and called 38°C "probably febrile" (historyofmedicine.com, search summary). The figures are secondary and his own methods were not read [VERIFY]. FO-07 records that his thermometer read high and that the modern mean oral temperature is 36.8°C, with a daily swing of about 0.5°C (THRIVING library, FO-07).

The record for the hand. Whybrew, Murray and Morley studied 1,090 children at Chikankata Hospital in Zambia against an axillary mercury thermometer left for exactly 3 minutes, with fever set at 37.8°C or more (the paper is in the BMJ, not the Lancet as the brief has it). Mothers felt 862 children. Their sensitivity was 94% and specificity 44%. A child they called "not hot" was truly afebrile 95% of the time, but only 39% of the children they called hot had fever. Two medical students did better on specificity (67%) with the same sensitivity (Whybrew and others 1998). Teng and colleagues reviewed the mother's touch in 2008 and found the studies too varied in method and cut-off to pool firmly (Teng and others 2008, record only). Later pooling gives sensitivity near 88% and specificity near 55% (THRIVING library, FO-07). The hand rules fever out. It cannot rule it in. Grade B.

The record for the glass. A salvaged clinical thermometer is the reference a village can hold. Galinstan, a gallium alloy used in mercury-free glass thermometers, behaves like mercury. In 120 hospital adults with 10-minute dwell times, the two agreed within a clinically trivial margin at every site (Smith 2003, search summary). In 284 Italian children, a galinstan thermometer in the armpit found fever with sensitivity 89.2% and specificity 98.0% against mercury, where a digital thermometer found only 67.5% (Italian paediatric study, search summary). Grade B.

Can a village make one? Blowing a fine capillary with a constriction that holds the highest reading is glass-works craft, and nothing in the record shows a village doing it [VERIFY, inference]. What a village can do is check the thermometers it holds. A general-purpose thermometer is checked at two fixed points. Crushed ice packed with a little water reads 0°C, and food-safety sources call this the more reliable check. Water at a full boil reads 100°C only at sea level. The boiling point falls about 1°C for every 300 m of altitude, and weather shifts it a little more. Clean smooth pots can superheat (Institute of Child Nutrition n.d., BYO n.d., both search summaries). A clinical thermometer scaled from 35 to 42°C cannot see either point, so the village checks it against a trusted reference thermometer in a bowl of warm water held near 38°C [VERIFY, inference]. That reference is the most valuable thermometer in the district, and it lives in a box.

What the thermometer misses. Fever is often absent in the old and septic. In 151 bacteraemic patients aged 75 or more (mean age 85), 21.2% had none of fever, low temperature, chills or low blood pressure, and this silent form was linked to death by day 7 and day 90 (Hyernard and others 2019, abstract). In older people with urinary infection that had reached the blood, 41.9% had no fever on arrival (Laborde and others 2021, search summary). Across 622 bacteraemic episodes in adults, fever was present in 78.4%, and age over 50 independently predicted its absence (Manian, Southern Medical Journal, search summary). One septic old person in five to two in five will have a normal thermometer reading. The thermometer adds a number, and the number must never outvote confusion, a fast breath, a fall or a refusal to eat.

2. Listening: paper, wood, horn and printed plastic

The tradition and the record. FO-07 tells the story of Laennec's rolled quire of paper at the Necker Hospital in 1816, the wooden cylinder about 25 cm long that followed, and the accuracy of chest signs heard by any means (THRIVING library, FO-07). This section adds only the instrument. A tube carries sound from a small patch of chest to the ear and cuts room noise. It does not make a sign more specific than the ear on the chest. Its main gains are decency, comfort, and hearing the heart and the fetus.

The modern maker case. Tarek Loubani, an emergency physician working in Gaza under blockade, led the Glia project, which printed a stethoscope in ABS plastic. On a phantom test it performed like the Littmann Cardiology III at all frequencies tested, cost under 3 US dollars and printed in under three hours (Pavlosky and others 2018, search summary). The comparison was acoustic, against one model, not a clinical trial. It shows that the bell and tube are not where the skill lies. After the Fall there is no printer, but the same shape can be turned in hardwood or made from salvaged rubber tubing and a funnel [VERIFY, inference].

The Pinard horn. A trumpet of wood or metal pressed on the pregnant belly lets the midwife hear the fetal heart from about mid-pregnancy [VERIFY]. Adolphe Pinard's name is attached to it from the 1890s, but the date was

not confirmed [VERIFY]. In Harare, Mahomed and colleagues randomised 1,255 women in labour to four kinds of monitoring. Hand-held Doppler detected abnormal fetal heart rates more reliably than the Pinard and was linked to good perinatal outcomes (Mahomed and others 1994, search summary). The Cochrane review of these trials found that Doppler and intermittent electronic monitoring led to more caesarean sections than routine Pinard listening, with a relative risk of 2.71 (1.64 to 4.48) for caesarean for fetal distress with Doppler, without clear benefit to mother or baby (Cochrane CD008680, search summary, authors not confirmed). A review of low-income settings found the lowest caesarean rates with the Pinard (10 to 15%) and comparable perinatal outcomes (Utrecht systematic review, search summary). WHO in 2018 recommended intermittent auscultation with either device for healthy women in labour, at very low certainty, priced the Pinard near one US dollar, and noted it needs practice-based training (WHO 2018, search summary). A secondary WHO teaching source gives the interval as every 15 to 30 minutes in active first stage and every 5 minutes in the second stage [VERIFY against the guideline]. The Pinard is the instrument a village can make and keep forever. Grade B.

3. Weight and the arm

Scales. A village weighs children to dose drugs, to see malnutrition and to see recovery. The Salter-type hanging scale in the MSF catalogue reads 0 to 25 kg in 100 g steps, is meant for children under 12, has an adjustment screw, and is to be checked daily with a test weight of at least 7 kg (MSF Unicat n.d., search summary). A training module warns that springs wear and overstretch, and that a scale should be re-zeroed before every child and read at eye level, to the nearest 100 g (Oppia training pages, search summary). A Philippine study of growth-monitoring scales found calibration and maintenance generally inadequate (UP study, search summary). The test weight costs nothing. A litre of water weighs about a kilogram, so seven litres in a tied bag or a marked jerrycan is a 7 kg check [inference from physics]. A beam balance or steelyard with a sliding weight has no spring to tire and can be made by a smith, and its accuracy depends only on the balance point and the known weights [VERIFY, inference]. No accuracy study of a home-made steelyard was found. Grade C for the made scale, B for the checked spring scale.

The arm. MA-07 sets the thresholds of mid-upper-arm circumference (under 115 mm severe, 115 to 125 mm moderate) and records that briefly trained mothers in Niger measured it as well as health workers with a colour-banded strap (THRIVING library, MA-07). A tape can be cut from paper or cloth and marked against a ruler. Cloth stretches and paper tears, so the village keeps a master strip and checks copies against it [VERIFY, inference]. Grade B.

4. Blood pressure: cuff, gauge and fingers

The record. Scipione Riva-Rocci described a cuff sphygmomanometer with a mercury column in the Gazzetta Medica di Torino in 1896, reading the systolic pressure where the wrist pulse disappeared (Healio 2009, search summary). One secondary source says he built it from copper pipe, bicycle inner tubes and a mercury barometer [VERIFY]. Harvey Cushing sketched the device in Pavia on 5 May 1901 and took it back to Johns Hopkins (Bause, Wood Library-Museum, search summary). Heinrich von Recklinghausen widened the cuff from 5 cm to 10 cm because the narrow cuff read high (Wikipedia, search summary). Nikolai Korotkoff, a Russian army surgeon, reported in 1905 that the sounds heard over the artery below the cuff gave both systolic and diastolic pressure (RMMA report 2025, search summary). The narrow cuff that read high in 1896 is the same error CH-02 measures today: the wrong cuff on a large arm adds up to 19.5 mmHg (THRIVING library, CH-02).

The gauge. Mercury columns hold their calibration. Dials do not. In an older British survey fewer than 2% of mercury instruments but 30% of aneroid dials were out by more than 4 mmHg (BMJ 1982, search summary). In 162 hospital dials in São Paulo, 56.2% failed the same test, more in public than private hospitals (Arquivos Brasileiros de Cardiologia, search summary). In Iranian hospitals about 54% did (Sabzevar study, search summary). A salvaged dial must therefore be checked, and the village has a way to do it without mercury. A clear tube bent into a U and half filled with water is a manometer. Mercury is about 13.6 times as dense as water, so 1 mmHg equals about 13.6 mm of water, and 150 mmHg shows as a difference of about 2 m between the two water levels [inference from physics,

VERIFY in use]. A tube fixed to a tall wall, teed into the cuff line, checks a dial at 100 and 150 mmHg.

Making a cuff. A cuff is a cloth sleeve, an airtight bladder inside it, a bulb with a one-way valve and a release screw, and a gauge. The bladder, bulb and valve can be salvaged from broken sets or bicycle parts and the sleeve sewn [VERIFY, inference]. No validation study of a home-made cuff was found. The bladder must reach most of the way round the arm (CH-02), so a village needs at least two sizes.

Without a stethoscope. The palpation method feels the radial pulse while the cuff is let down and reads systolic pressure where it returns. It reads systolic only, and usually a little low [VERIFY]. In 200 Indian surgical patients, a palpatory method for both pressures came within 2 mmHg of the ear in 51% of patients (Sahu and Bhaskaran 2010, abstract). The palpation first also guards against the auscultatory gap, a silent stretch in the sounds that makes the listener stop too early [VERIFY]. Grade B for the checked cuff, C for palpation alone.

5. The microscope: bead, paper and brass

Leeuwenhoek. Antoni van Leeuwenhoek in Delft saw bacteria in the 1670s with single lenses held in a brass plate. The strongest survivor, in Utrecht, magnifies about 266 times and resolves a little over one micrometre, and van Zuylen proposed that it was blown from hot glass rather than ground (van Zuylen 1981, search summary). A single small sphere of glass is therefore an old and real microscope, but its field is tiny and holding the sample in focus is slow.

The Foldscope. Cybulski, Clements and Prakash built a microscope from a punched and folded paper sheet holding a ball lens. Lenses gave 140 to 2,180 times. Measured resolution was 2.19 μm at 140 times and 1.38 μm at 430 times, with submicron resolution at higher power. The field of view at 1,450 times had a radius of only 88 μm. It weighed 8.8 g, cost under one US dollar in parts at scale (0.58 to 0.97), assembled in under 10 minutes, survived a three-storey drop, and its LED ran over 50 hours on a coin cell. The authors imaged Giardia, Leishmania, Trypanosoma, Schistosoma haematobium eggs and a Giemsa-stained blood film, but used no human samples and reported no sensitivity or specificity, calling it early bench work (Cybulski and others 2014). In the one field test found, in Ghana, a phone-mounted Foldscope found S. haematobium eggs in urine with sensitivity 55.9% and specificity 93.3% against a conventional microscope, on 49 samples. A reversed phone lens did better at 67.6% and 100% (Ephraim and others 2015, search summary). A review blamed the small field and the difficulty of moving the slide (mobile microscopy review 2017, search summary). No field study of the Foldscope for malaria was found. The claim is a two-thousand-power microscope for a dollar. The record is a bench paper and one small field study that missed nearly half the infections. The inference is that a paper microscope is a teaching and curiosity tool and a backup for large targets such as worm eggs, not a malaria instrument. Grade C.

The salvaged compound microscope. The WHO manual asks for paired ×10 eyepieces and a ×100 oil-immersion objective. A monocular microscope with a mirror works by daylight with no power, while binocular heads are poorly lit by daylight (WHO 2010). Fungus grows on lenses in warm damp air and can ruin them. The manual's remedies are a warm cupboard held at 30 to 35°C by burning bulbs, an airtight box with silica gel that is dried by heating when it turns pink, or air conditioning (WHO 2010). After the Fall the silica-gel box is the one that lasts, and a dry season is the time to clean the optics [VERIFY, inference]. Immersion oil, glass slides and lens tissue are consumables to stockpile (THRIVING library, OR-06).

6. What a microscopist can read, and after how long

Malaria. The WHO Learner's Guide is the foundation for a formal course of 4 to 5 weeks for people with only elementary science (WHO 2010, publisher page). A thick film is negative only after 100 good oil-immersion fields have been read, which takes about 10 minutes. If parasites are seen but the species is uncertain, 100 more are read. A thin film needs at least 800 fields, about 30 minutes, to match the thick film. Parasites are counted against 200 white cells and multiplied by 8,000 to give parasites per microlitre (WHO 2010). Giemsa is used at 10% for 8 to 10 minutes

for a quick result or 3% for 45 to 60 minutes for batches, in water buffered to pH 7.2. Water must never enter the stock bottle, and the methanol used to fix thin films is toxic and can blind (WHO 2010). Field's stain, used as quick dips of a few seconds each, is the faster alternative, and timings vary by source from 1 to 5 seconds per solution (stain protocols, search summaries).

The record in ordinary hands is poor. In Dar es Salaam, Kahama-Maro and colleagues re-read 335 routine slides from 12 public facilities. Routine laboratories called 53.1% positive, experts 2.1%. Sensitivity was 71.4% and specificity 47.3%, so only 2.8% of routine positives were true. Staff read 100 to 200 slides a day, with poor microscopes, poor reagents and no supervision, and probably took stain debris for parasites (Kahama-Maro and others 2011). After a seven-day course in Nigeria, laboratory staff agreed with experts on positive or negative barely half the time (THRIVING library, OR-01). Even experts miss low densities. A thick film's practical limit in Gabon was 62 to 88 parasites per microlitre (THRIVING library, IN-09). In a Kenyan pilot, experts reached full sensitivity only above about 200 parasites per microlitre and qualified readers above about 500 (Malaria Journal thin-film pilot, search summary). Expert thick films found fewer infections than quantitative PCR predicted, and parasites were lost in staining (Malaria Journal 2006, search summary).

Lay readers have done it with a system behind them. From 1999 the Kilusan Ligtas Malaria movement in Palawan in the Philippines trained 344 community health workers as village microscopists, one per endemic village, with refresher courses, and malaria deaths and illness fell sharply (Matsumoto-Takahashi and others 2013, abstract, and 2016 review, search summary). No figure for their reading accuracy was found. By contrast, 64 village volunteers in Laos with no laboratory experience performed two rapid tests with under 2% reading error after one hour of training (Mayxay study, search summary). The rapid test, not the microscope, is the lay test while stocks last. Grade A for the film as the reference standard in trained, checked hands, D in an unsupervised lay reader's hands.

Tuberculosis. The Ziehl-Neelsen method stains acid-fast bacilli red with hot carbol fuchsin, decolours the rest with acid alcohol and counterstains with methylene blue. Carbol fuchsin contains phenol, which burns skin. A positive smear needs about 5,000 to 10,000 bacilli per millilitre, and two specimens find about 89% of those a smear will ever find (THRIVING library, IN-10). Steingart and colleagues reviewed 45 studies. Against culture, ordinary smear sensitivity ranged from 32% to 94%, and the background literature gave 20 to 60% in routine use. Fluorescence microscopy was on average 10% more sensitive, with similar specificity (Steingart and others 2006). The brief's "about half" is fair for routine conditions. A smear finds the most infectious patients and misses the rest by design. Grade B.

Stool. Single stools miss many infections because eggs come and go. For hookworm, one Kato-Katz sample found about 50% of infections, two 75%, three 85% and four 95%. For Schistosoma mansoni at 100 eggs per gram, one sample found 50% and two 80%, and very light infections were missed even after three (Bärenbold and others 2017, search summary). A simple wet mount in saline or iodine is less sensitive again [VERIFY]. Grade B for the method, with the rule that one negative stool means little.

Urine. A microscope adds schistosome eggs, pus cells and casts to the bench. In Ghana, filtering urine through a single sheet of paper towel instead of centrifuging gave 67.6% sensitivity and 80% specificity for S. haematobium eggs (Ephraim and others 2015, search summary). Settling urine in a conical glass for an hour may stand in for a centrifuge [VERIFY]. Grade C.

Gram stain. Gentian violet (crystal violet) is the first dye of Gram's method. The method also needs iodine, an alcohol or acetone decolouriser and a red counterstain. In men with urethral discharge, a smear showing Gram-negative diplococci inside pus cells had sensitivity 94% and specificity 100% for gonorrhoea, but only 40% sensitivity in women (UK comparison, search summary). A 2012 Spanish study found 80% sensitivity for gonorrhoea in symptomatic men and far less for other causes of urethritis (Sex Transm Infect 2012, search summary). Grade B for men with discharge, D otherwise.

7. Urine chemistry: sugar, protein, ketones and strips

Sugar. CH-01 holds the recipe for Benedict's reagent, the colour bands and the rule that urine sugar may raise an insulin dose but must never lower one (THRIVING library, CH-01). This report adds accuracy. Benedict's reagent detects any reducing sugar, not glucose alone, and the kidney spills glucose only above about 10 mmol per litre (THRIVING library, CH-01). As a screen for diabetes in people without symptoms, urine glucose testing is specific but insensitive. Recalculated sensitivities were 34% and 50% in two studies, and a lower-risk antenatal cohort gave 36% with specificity 98% (BestBETs n.d., search summary). In pregnancy, false positives outnumbered true ones 11 to 1 for gestational diabetes (JFP review, search summary). The test confirms diabetes in a thirsty, thin, frequent passer of water. It does not find early or controlled diabetes. Grade B for confirmation, X for reassurance.

Protein. Bright's test is boiling the top of a tube of urine and looking for a white cloud. A few drops of dilute acetic acid, which household vinegar supplies, clear the harmless cloud of phosphates and carbonates and leave protein (teaching sources, search summary). Dissanayake and colleagues validated the heat test in 102 pregnant women in Sri Lanka against 24-hour urine. A heat test of 1+ or more was as sensitive and specific as a dipstick of 2+ for protein of 500 mg a day or more, but missed lesser amounts that a 1+ dipstick found (Dissanayake and others 2004, abstract). An Indian comparison found fewest false positives and slightly more false negatives with the heat test than with dipsticks (JCDR, search summary). FO-07 marked the vinegar step unconfirmed (THRIVING library, FO-07). It is confirmed here in teaching sources and in the Sri Lankan method name, though the exact quantity was not read in a primary source [VERIFY]. The heat test needs a glass tube, a flame and vinegar, and it never expires. Grade B for heavy proteinuria in pregnancy.

Ketones. The nitroprusside reaction (Rothera's test and the ketone pad on strips) detects acetoacetate and acetone, down to about 1 to 2 mg per dl of acetoacetate, but not beta-hydroxybutyrate, which dominates early ketoacidosis (Clinical Methods, NCBI Bookshelf, search summary). A weak ketone result can therefore understate a serious acidosis. CH-01 records that a fifth to a third of people cannot smell acetone (THRIVING library, CH-01). Nitroprusside powder is a salvage item, not a village product. Grade B as a positive sign, C as a negative.

Strips past their date. In an emergency department study, strips left open to room air for 1 to 15 days kept their readings for leucocytes, pH, protein, glucose, ketones, urobilinogen, bilirubin and blood, but one third of nitrite pads read falsely positive after a week (study of dipsticks stored in open containers, search summary). Manufacturers set dates after opening, and one hospital policy gives 30 days at room temperature, which is a local rule, not a standard (Johns Hopkins competency sheet, search summary). Glucose meter strips carry an enzyme. Strips stored in simulated Thai hospital conditions, over 30°C and 84% humidity, read differently from controls, and no validated grace period exists (manufacturer summary of a 2021 study, secondary). The rule after the Fall: test every opened tube of strips against a known sample, such as water (negative) and a sugar solution (positive), before trusting a negative [VERIFY, inference]. Grade B for fresh strips, D for strips past date without a check.

8. Blood: colour, weight and groups

The haemoglobin colour scale. Stott and Lewis printed a card of ten shades of blood from about 4 to 14 g/dl, matched against a drop of blood on absorbent test paper (Stott and Lewis 1995, abstract). The brief's figure of "about 1 g/dl" is the design target, not the field result. In four district hospitals in Malawi, Medina Lara and colleagues compared six methods against the reference. Only 57% of colour-scale readings fell within 1 g/dl of the truth, and 16% were wrong by more than 2 g/dl. It took 160 minutes to train a laboratory attendant, about 3 minutes a test, and cost 0.12 US dollars a test (Medina Lara and others 2005). Critchley and Bates found 14 studies, with sensitivity 75 to 97% and specificity 41 to 98%, and better accuracy in laboratory studies than in real clinics (Critchley and Bates 2005, abstract). Marn and Critchley pooled primary-care studies. The scale found anaemia with sensitivity 80% and specificity 80%, against 52% and 75% for clinical judgement of pallor. For severe anaemia it found 57%, with specificity 99.6% (Marn and Critchley 2016, abstract). Yet in 799 children in rural Zanzibar, health workers using the scale found only 33% of anaemic children and 14% of the severely anaemic, against a portable meter (Aldridge and

others 2012, abstract). The scale is cheap, quick, and better than the eye, but it can miss most anaemia in some hands. The card itself is printed with special dyes and paper and cannot be reprinted in a village. Grade B for screening in trained hands, with a warning for children.

The Sahli method. Sahli's haemoglobinometer turns blood brown with dilute hydrochloric acid in a graduated tube and adds water until the colour matches a glass standard. It needs a 20 µl pipette, the tube, the comparator and the acid. In 173 Indian students, it read 0.62 g/dl low on capillary and 1.1 g/dl low on venous blood against the reference, with sensitivity 84 to 90% and specificity 60 to 63% for anaemia (Patil and others 2013). In 292 hospitalised children in eastern Uganda, it found severe anaemia with sensitivity 84.0% and specificity 87.9% against a portable meter, kappa 0.70, at 0.25 US dollars a test against 4 dollars (Olupot-Olupot and others 2018, abstract). The glass parts last for ever if not broken. The acid is the limit, and a village cannot make it safely [VERIFY, inference]. Grade B.

The copper sulphate drop. Blood banks drop blood into copper sulphate solution of set specific gravity, and a drop that sinks has enough haemoglobin. Results conflict wildly. In 520 Thai donors it had sensitivity 99.7% and specificity 63.4% (Thai blood bank study 2011, abstract). In 263 donors in Lagos it had sensitivity 40.5% and specificity 86.4%, which its authors judged too low to use (Lagos study, search summary). High serum protein, high white count and heat all disturb it (search summaries). It needs a weighed salt, a specific-gravity check and fresh solution, and it answers only "enough or not". Grade C.

Grouping and the bedside crossmatch. Slide grouping mixes a drop of blood with anti-A and anti-B sera on a tile and looks for clumping. Reagent inserts warn that slide methods are unsuitable for weak D, that negative slide results should be confirmed in tubes, and that weak A types can be misread as group O unless anti-A,B is added (FDA-cleared reagent inserts, search summary). Salvaged antisera have expiry dates and need cold storage [VERIFY]. A crossmatch mixes the recipient's serum with the donor's cells and looks for clumping. One teaching deck describes an immediate-spin crossmatch read after 5 minutes at room temperature (Malaysian transfusion deck, search summary). King's Primary Surgery is widely cited for a bedside crossmatch at district level, but the text could not be found or read, and its method is not reported here [VERIFY]. MA-02 covers when to transfuse after birth (THRIVING library, MA-02). Grade C.

9. The battery instruments

Pulse oximeter. It gives oxygen saturation and pulse rate from a finger and runs on two small cells. In patients whose meter read 92 to 96%, arterial blood showed less than 88% in 11.7% of Black patients against 3.6% of white patients, nearly three times the hidden hypoxaemia (Sjoding and others 2020, search summary). On dark skin a normal reading reassures less. Batteries, not the sensor, end its life. Grade A for the device while it lasts, with that caveat.

Glucose meter. It answers what urine cannot: is the sugar falling? Its strips are the limit (section 7). When strips end, CH-01's urine rules take over.

Ophthalmoscope and otoscope. Hermann von Helmholtz's ophthalmoscope is dated 1851 in the brief, which was not confirmed here [VERIFY]. A direct ophthalmoscope in trained hands shows the red reflex, cataract, haemorrhages and swelling of the disc. Its accuracy for diabetic eye disease and for disc swelling in non-specialist hands varies widely between studies and is too low to replace a specialist, and no figure was confirmed here [VERIFY]. Both need bulbs and cells. A head mirror and daylight was the pre-electric otoscope [VERIFY]. These belong at the district while batteries last (CH-02 places the ophthalmoscope there).

Evidence grades

Instrument or test	What it does	Accuracy in the record	Grade
Hand on forehead	Rules fever out	Sens 94%, spec 44% (mothers, Zambia)	B
Glass thermometer, checked	Measures fever	Galinstan sens 89%, spec 98% vs mercury	B
Thermometer in septic elderly	Detects sepsis	Fever absent in 21 to 42%	X as reassurance
Paper or wooden tube	Chest and heart	Equal to the ear, adds decency	B
Pinard horn	Fetal heart	Fewer caesareans than Doppler, outcomes comparable	B
Spring scale, checked daily	Weight	100 g steps, springs tire	B
Home-made steelyard	Weight	No study found	C
MUAC strip	Malnutrition	Mothers equal to health workers (MA-07)	B
Mercury or checked aneroid cuff	Blood pressure	Unchecked dials out by more than 4 mmHg in 30 to 56%	B
Palpation only	Systolic pressure	Within 2 mmHg in 51% (one study)	C
Foldscope	Magnifies	Sens 56% for urine eggs, no malaria data	C
Thick film, trained and checked	Malaria	Reference standard, limit about 60 to 90 parasites per µl	A
Thick film, unchecked	Malaria	Sens 71%, spec 47%, PPV 3% (Dar es Salaam)	D
Ziehl-Neelsen smear	Infectious TB	Sens 32 to 94% vs culture	B
Kato-Katz, one stool	Worms	About 50% sensitivity	B
Gram smear, male discharge	Gonorrhoea	Sens 80 to 94%, spec near 100%	B
Benedict's test	Sugar in urine	Specific, insensitive as a screen	B confirm, X reassure
Heat and vinegar	Protein	Equal to dipstick 2+ for 500 mg a day	B
Nitroprusside	Ketones	Misses beta-hydroxybutyrate	B positive, C negative
Dipstick past date	Several	Nitrite false positive a third after a week	D unchecked
Colour scale	Haemoglobin	57% within 1 g/dl, sens 33 to 80%	B adults, C children
Sahli	Haemoglobin	Reads 0.6 to 1.1 g/dl low, sens 84% for severe	B
Copper sulphate drop	Haemoglobin enough or not	Sens 41 to 99.7%	C
Slide grouping	ABO and D	Misses weak D and weak A	C

Instrument or test	What it does	Accuracy in the record	Grade
Pulse oximeter	Oxygen	Hidden hypoxaemia 3 times commoner on dark skin	A while cells last

Means ledger

Rung	Instruments and tests	What it changes
Hands and knowledge	Hand for fever, ear on chest and belly, fingers on the pulse	Rules fever out, counts breaths and pulse (FO-07)
Hearth	Paper tube, Pinard horn of wood, cloth MUAC strip, litre jug as weight, spoon and candle with vinegar for protein, ants or Benedict's for sugar (CH-01)	Hears the fetus, finds malnutrition, finds heavy protein in pregnancy
Garden and still	Salvaged glass thermometer checked in ice and warm water, steelyard or checked spring scale, turned wooden stethoscope, water U-tube manometer	Measured fever, weight for doses, a dial checked without mercury
Village dispensary (300)	Five thermometers (OR-06), cuffs in two sizes, colour-scale cards, strips while they last, rapid malaria tests while they last, a register	Anaemia screened, pressure measured in pregnancy, malaria confirmed while kits last
District infirmary (3,000)	Oil-immersion microscope, Giemsa or Field's stain, Ziehl-Neelsen kit, Sahli set, grouping sera, oximeter and meter while cells last, a trained microscopist with a reference reader (OR-07)	Confirms malaria and cure, finds infectious TB, measures haemoglobin before transfusion
Pre-Fall hospital	Automated counts, culture, PCR, imaging, continuous monitoring	Finds what every rung above misses, at the cost of supply chains the village does not have

Each rung changes outcomes less by the instrument than by the check behind it. A microscope without a reference reader can do more harm than none, as Dar es Salaam showed. A Pinard used every half hour by a midwife who knows what a slow heart means saves more babies than a Doppler with flat batteries.

Harm test

False reassurance. The septic old person with a normal temperature. The anaemic child whose colour card matched 11 g/dl. The "negative" film read on 20 fields or badly stained. The diabetic with clear urine whose blood sugar is falling towards a fit. The pregnant woman whose weak protein test missed early pre-eclampsia. In every case the sign that should have acted was overruled by a number. **What to do:** every protocol below states the clinical signs that override the test.

False alarm. Dar es Salaam's routine slides called a quarter of all fevers malaria that were not, so the real cause went untreated and the drug was spent (Kahama-Maro and others 2011). Old nitrite pads call urine infected when it is not.

Mercury. A fever thermometer holds under a gram of mercury [VERIFY]. The danger is vapour in a warm closed room, mostly for young children and pregnant women. Never vacuum or sweep it, gather beads with card and tape, ventilate for at least 24 hours and keep children out (EPA 2017). A New Jersey county document notes that serious illness and death from thermometer mercury are recorded, mostly in young children (county guidance, search summary). Store mercury instruments in a padded box and never give one to a child to hold in the mouth.

Glass and sharps. Broken thermometers cut mouths and rectums. Use the armpit in children under five and in anyone confused or fitting [VERIFY]. Lancets and capillary tubes for films and colour cards carry blood-borne infection. One lancet per patient, boiled or burned after use, under WO-12's rules (THRIVING library, WO-12).

Chemicals. Methanol blinds and kills if swallowed (WHO 2010). Carbol fuchsin burns. Copper sulphate poisons, and boiling urine spits (THRIVING library, CH-01). Hydrochloric acid for Sahli burns. All go in the locked poisons cupboard (THRIVING library, OR-08), labelled, away from food bottles.

Wrong cuff, wrong dial. Up to 19.5 mmHg too high on a large arm (CH-02), or 4 mmHg and more on a drifted dial. A treatment decision made on one wrong reading can start a drug a person does not need, or miss pre-eclampsia.

Who must never receive the test as the decider. Infants, the old, the pregnant and the dark-skinned are where the instruments lie most often: the infant's fever missed by touch, the elder's sepsis without fever, the child's anaemia missed by the card, the dark-skinned patient's low oxygen read as normal.

Historical harm. The Dar es Salaam over-diagnosis is the clearest record: 53% called positive, 2% true (Kahama-Maro and others 2011). The Lagos copper sulphate drop passed six of ten unfit donors (Lagos study, search summary).

Red flags

These signs mean the patient needs what the instruments cannot give, and they override every reading.

1. Confusion, a fall or refusal to eat in an old person, whatever the thermometer says: treat as sepsis (THRIVING library, IN-02 and FO-07).
2. A child with fever in a malarious season and danger signs: treat for severe malaria at once, film or no film (THRIVING library, IN-09).
3. A pregnant woman with headache, blurred sight or swelling of face and hands and a pressure of 140 over 90 or more on a checked cuff, or with heavy protein on heat: pre-eclampsia (THRIVING library, MA-04).
4. A fetal heart under 110 or over 160 that persists after a contraction [VERIFY]: the baby is in danger.
5. Pallor of palms and inner eyelids with breathlessness at rest, whatever the card says: severe anaemia.
6. Ketones on the breath or the stick with vomiting or deep breathing: ketoacidosis (CH-01).
7. Cough over two weeks with weight loss and a negative smear: still possibly tuberculosis (IN-10).
8. An oximeter reading under 90% or blue lips: the village cannot give oxygen for long. Sit the patient up, keep them warm, and give honest comfort when it fails.

Honest comfort. Many of these flags mean the village knows earlier, not that it can cure. Knowing earlier still allows a journey to the district, a drug given in time, or a family gathered.

The case against

Against home-made instruments. Maker culture produces devices faster than it produces accuracy data. The Foldscope paper itself said it had no human samples (Cybulski and others 2014), and its one field test missed 44% of infections (Ephraim and others 2015). The Glia stethoscope was tested on a phantom. Manu Prakash's team and

Tarek Loubani's are honest about this, but the press was not (Pavlosky and others 2018, press coverage summary). A village should not believe an instrument because it is clever.

Against the microscope in the village. OR-01 excluded microscopy from the 300 hours because a week's course gives agreement with experts barely better than a coin toss (THRIVING library, OR-01). Kahama-Maro and colleagues show that bad microscopy is worse than none. Lengeler's group, who wrote that paper, argued for rapid tests and quality assurance rather than more microscopes (Kahama-Maro and others 2011). The case for a microscope after the Fall is only that rapid tests run out. It holds at the district, with a reader trained over weeks, a second reader and a slide bank.

Against the colour scale. Paddle argued in the Bulletin of the WHO in 2002 that the scale's accuracy was poor, and Cherian and colleagues replied that it was a clinical aid, not a replacement for a laboratory (Bulletin correspondence 2002, search summary). Aldridge's Zanzibar figure of 33% sensitivity supports the critic for children.

Against urine testing. Urine sugar lags and cannot see a falling glucose. Everyone dropped it when blood strips came (THRIVING library, CH-01). The reply is the same as CH-01's: after the strips, the alternative is no measurement.

Against the romance of the hospital. Doppler found more abnormal heart rates than the Pinard in Harare, yet the Cochrane review found more caesareans without better babies. More signal is not always more health.

10-line summary

1. The hand rules fever out (sensitivity about 90%) but cannot rule it in. A checked glass thermometer is the reference a village can keep.
2. One septic old person in five to two in five has no fever. No thermometer reading overrules confusion or a fall.
3. A paper tube, a turned wooden cylinder and a Pinard horn give most of what a stethoscope gives. The Pinard is a forever instrument.
4. A spring scale is checked daily against 7 litres of water. A steelyard is the forge's version.
5. Aneroid dials drift: 30 to 56% are out by more than 4 mmHg. A 2 m water U-tube can check one without mercury.
6. The Foldscope is a real magnifier but missed 44% of urine fluke eggs and has no malaria data.
7. Malaria film reading takes a 4 to 5 week course and a second reader. Without checking, routine films in Dar es Salaam were 97% wrong when positive.
8. The tuberculosis smear finds 32 to 94% of culture-positive cases, the infectious ones. One stool finds about half of worm infections.
9. Heat and vinegar find heavy protein in pregnancy and never expire. Benedict's confirms diabetes but cannot reassure. Nitroprusside misses the main ketone.
10. The colour scale is within 1 g/dl only 57% of the time and missed two thirds of anaemic children in Zanzibar. Sahli reads about 1 g/dl low and lasts.

Open questions

- How accurate is a home-made cuff with a salvaged dial, checked against a water manometer? No study was found.
- Can lay village microscopists read malaria films reliably with a district reference reader? Palawan suggests yes, but no accuracy figures were found.
- How long do Giemsa stock, Field's stains, grouping sera and the colour-scale card last in heat without a refrigerator?
- What is the accuracy of a home-made steelyard or beam balance for infant weights?
- Does the heat test, with a fixed quantity of vinegar, keep its Sri Lankan accuracy in lay hands?
- King's bedside crossmatch: what exactly does Primary Surgery say? Not read.

- Can a paper towel filter and a salvaged microscope replace the centrifuge for urine and stool? One small study only.

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At the bedside after the Fall

Household. Needs: a hand, a cloth MUAC strip marked at 115 and 125 mm (MA-07), a clock or pendulum (FO-07), a tube of rolled paper, and if possible one glass thermometer in a padded box. Skills: feel for fever and use "not hot" to rule out, take an armpit temperature for 3 to 4 minutes (FO-07), measure the arm, listen through the tube. Records: a card per child with weight and arm. First failure to expect: the thermometer breaks in a child's mouth, or a normal reading sends an old person with a urinary infection back to bed.

Village of 300. Needs: five thermometers and one reference thermometer (OR-06), a hanging scale and a 7 litre test weight, two cuffs in two sizes with a mercury column or a water U-tube for checking, a Pinard horn, colour-scale cards, Benedict's reagent (CH-01), vinegar, glass test tubes and a spirit lamp, rapid malaria tests and urine strips while they last, a sharps tin and a register. Skills: temperature, weight, pressure by palpation and by ear, the fetal heart, the heat test, the colour card, reading rapid tests. No microscope in the dispensary unless its reader has been signed off at the district [OWNER]. First failure to expect: the strips and rapid tests are used past their date without a check, and a negative is believed.

District of 3,000. Needs: one or two oil-immersion microscopes kept in a silica-gel box, Giemsa and Field's stain, a Ziehl-Neelsen kit, glass slides, immersion oil, a Sahli set, grouping sera, an oximeter and a glucose meter while cells and strips last, a slide bank of known positives for teaching and checking, and a microscopist trained over 4 to 5 weeks with a second reader who re-reads one slide in ten [OWNER]. The bench as a room belongs to OR-07. First failure to expect: the stain runs out or goes bad, staining debris is read as parasites, and the district starts calling every fever malaria.

Protocols

Protocol 1. The instrument kit [OWNER for quantities]

Item	Household	Village of 300	District of 3,000
Clinical thermometer	1	5 plus 1 reference	10 plus 1 reference

Item	Household	Village of 300	District of 3,000
Paper or wooden tube, Pinard horn	1 tube	2 of each	4 of each
MUAC strip	1 per child	10, with a master	20, with a master
Hanging scale, 25 kg in 100 g	0	1, plus 7 litre test weight	2 plus an infant pan
Cuff with gauge, two sizes	0	2	4, plus mercury column or water U-tube
Colour-scale cards and test paper	0	1 book	2 books
Glass tubes, spirit lamp, vinegar	0	12 tubes	24 tubes
Microscope with ×100 oil objective	0	0 [OWNER]	1 to 2
Stains, slides, oil, lancets	0	lancets only	a year's supply (OR-06)

Protocol 2. Checking a thermometer

- ☐ General thermometer: fill a cup with crushed ice and a little cold water. Stir. After 3 minutes it must read 0°C, within 0.5°C [VERIFY tolerance].
- ☐ Boiling check, if needed: subtract 1°C for every 300 m above sea level from 100°C. Use a pot with a rough bottom or a pebble to stop superheating.
- ☐ Clinical thermometer: warm water in a bowl, near 38°C. Put the reference thermometer and up to five others in together. Wait 3 minutes. Any that differ from the reference by more than 0.2°C [VERIFY tolerance] are marked and taken out of use.
- ☐ Write the date and result on the ledger. Repeat every three months and after any fall.

Protocol 3. Taking a temperature

- ☐ Feel first. If the patient feels "not hot" and is well, fever is unlikely.
- ☐ Shake the glass thermometer down below 35°C. Clean with alcohol or soap and water.
- ☐ Armpit for children under five and anyone confused or fitting. Dry the armpit, hold the arm against the side for 3 to 4 minutes (FO-07). Galinstan glass may need longer [VERIFY].
- ☐ Fever is 37.8°C or more in the armpit (Whybrew and others 1998). A newborn under 36°C is also danger (FO-07).
- ☐ In anyone over 65, a normal temperature does not rule out infection. Look for confusion, fast breathing, a fall, new incontinence, refusal to eat.
- ☐ If the thermometer breaks: keep children away, gather beads with card and tape, never sweep or vacuum, ventilate 24 hours.

Protocol 4. Blood pressure

- ☐ Check the dial each quarter against a mercury column or the water U-tube at 100 and 150 mmHg. Out by more than 4 mmHg: take it out of use (CH-02).
- ☐ Choose the cuff whose bladder goes most of the way round the arm (CH-02). Bare arm, supported at heart level, patient seated 5 minutes.
- ☐ Feel the radial pulse. Pump the cuff until the pulse goes, then 30 mmHg more [VERIFY]. Let it down about 2 mmHg a second. Where the pulse returns is the systolic pressure by palpation.

- ☐ With a stethoscope or tube over the inner elbow, pump again to 30 mmHg above that point. The first tapping sound is systolic, the point where sounds vanish is diastolic (Korotkoff).
- ☐ Take two readings a minute apart and write both.

Protocol 5. The thick film at the district

- ☐ Prick the finger with a fresh lancet. Place a drop of blood on a clean slide and spread it into a circle about the size of a small coin with the corner of another slide [VERIFY size].
- ☐ Dry flat, away from flies and heat. Do not fix a thick film.
- ☐ Stain with Giemsa 10% in buffered water at pH 7.2 for 8 to 10 minutes, or 3% for 45 to 60 minutes for batches (WHO 2010). Or Field's stain by quick dips, by the bench's own timing.
- ☐ Rinse gently, dry upright.
- ☐ Read under oil with the ×100 objective. Read 100 good fields, about 10 minutes, before calling it negative (WHO 2010).
- ☐ If positive, count parasites against 200 white cells and multiply by 8,000 for parasites per µl.
- ☐ A second reader re-reads every positive and one negative in ten [OWNER].
- ☐ A negative film never stops treatment of a child with danger signs.

Protocol 6. Urine at the bench

- ☐ Look: colour, cloudiness, visible blood (FO-07).
- ☐ Protein: fill a glass tube two thirds with urine. Heat the top third over a spirit flame until it boils, holding the tube by a cloth, mouth away from faces. Cloud in the top: add 3 drops of vinegar [VERIFY quantity]. Cloud stays: protein. Thick cloud: heavy protein.
- ☐ Sugar: Benedict's by CH-01 Protocol 1.
- ☐ Ketones: strip or nitroprusside if held. A trace with deep breathing is not reassurance.
- ☐ Strips: check each opened tube weekly with water (should be negative) and with a spoon of sugar in a cup of water (glucose pad should turn) [VERIFY, inference]. Ignore nitrite pads on tubes open more than a week.

Protocol 7. Haemoglobin by colour scale

- ☐ Use only the scale's own test paper.
- ☐ Wipe away the first drop, put the second drop on the paper.
- ☐ Wait about 30 seconds, until the shine goes, and read before 2 minutes [VERIFY timing].
- ☐ Read in daylight, not direct sun, holding the paper behind the card's aperture.
- ☐ Write the nearest shade. Below 7 g/dl, or pallor with breathlessness whatever the shade: severe anaemia.
- ☐ In children, a normal shade does not rule out anaemia (Aldridge and others 2012). Look at palms and eyelids too.

Protocol 8. Keeping the instruments

- ☐ Microscope: in an airtight box with silica gel. Bake the gel in a pot when it turns pink. Wipe oil off the lens after each session.
- ☐ Stains: dark glass, tight stopper, cool shade, small daily bottle, no water in the stock (WHO 2010).
- ☐ Mercury instruments: padded box, out of children's reach.
- ☐ Batteries: removed from oximeters and meters in storage.
- ☐ Every instrument has a line in the register: date checked, by whom, result.

Numbers to carry

1. Armpit fever: 37.8°C. Feeling "not hot" rules fever out about 95% of the time.

2. Up to 2 in 5 septic old people have no fever.
3. Boiling point falls 1°C for every 300 m of height.
4. 1 litre of water is 1 kg. 1 mmHg is 13.6 mm of water.
5. A dial out by more than 4 mmHg leaves service. Wrong cuff: up to 19.5 mmHg high.
6. 100 fields, about 10 minutes, before a thick film is negative. Parasites per 200 white cells times 8,000.
7. A tuberculosis smear finds between a third and nine tenths of cases. Two specimens.
8. One stool finds about half of worm infections.
9. Colour scale: within 1 g/dl only 57% of the time. Sahli reads about 1 g/dl low.
10. Nitrite pads go false after one week open.

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