RATIONAL TESTING

Investigation of incidental hypercalcaemia

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Hypercalcaemia is often asymptomatic, but if it is suspected, various tests can provide guidance to confirm diagnosis and identify the likely cause

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This series of occasional articles provides an update on the best use of key diagnostic tests in the initial investigation of common or important clinical presentations. The series advisers are Steve Atkin, professor, head of department of academic endocrinology, diabetes, and metabolism, Hull York Medical School; and Eric Kilpatrick, honorary professor, department of clinical biochemistry, Hull Royal Infirmary, Hull York Medical School.

The patient

A 50 year old woman is found to have hypercalcaemia on routine blood tests. Her corrected calcium concentration was 2.75 (reference range 2.10-2.60) mmol/l, and phosphate 0.7 mmol/l (0.7-1.4) mmol/l. She had no history of abdominal pain, constipation, renal calculi, fractures, or mood disturbances. She was euvolaemic with no signs of chronic renal disease. Routine laboratory tests—including full blood count, serum electrolytes, and renal and liver function—were normal.

As her hypercalcaemia was mild, she did not require immediate measures to correct this. Investigations to determine the cause of the hypercalcaemia were performed.

About 40-50% of serum calcium is bound to protein (mostly albumin), and the remaining calcium is free or ionised (the portion under hormonal regulation). Corrected calcium is calculated from total calcium and serum albumin and an accurate reflection of ionised calcium in an individual with a normal serum albumin and normal acid-base balance. Asymptomatic hypercalcaemia (based on corrected or ionised values) is nowadays a common diagnostic and management dilemma, with more patients undergoing routine blood tests for other purposes. However, not all cases require treatment.

Primary hyperparathyroidism and malignancy together account for 90% of all hypercalcaemic patients.[1] Aetiology varies according to the clinical presentation; more indolent cases suggest hyperparathyroidism, and more rapidly developing cases suggest malignancy. About 20-30% of all patients with cancer develop hypercalcaemia at some time as a paraneoplastic phenomenon or as a result of bone metastases.[2] Dehydration exacerbates underlying hypercalcaemia by reducing renal calcium excretion, and drugs such as thiazide diuretics[4] and lithium may exacerbate the underlying hypercalcaemia of primary hyperparathyroidism. The box outlines other causes of hypercalcaemia.

Causes of hypercalcaemia

Most common causes

- Primary hyperparathyroidism—commonest cause of hypercalcaemia in the community if renal function is normal and the patient is euvolaemic (community incidence 0.1-0.3%[2 3])
- Malignancy (myeloma, metastatic bone disease)—suggested by rapidly progressive hypercalcaemia

Less common causes*

- Tertiary hyperparathyroidism in renal disease
- Granulomatous disease (sarcoidosis, tuberculosis)
- Lymphoproliferative disorders
- Vitamin D toxicity (seen with high dose vitamin D but now rare)
- Thyrotoxicosis
- Addison's disease
- Milk alkali syndrome resulting from heavy calcium load and secondary renal damage (now rare with the use of H_2 antagonists rather than calcium based antacids)
- Familial hypocalciuric hypercalcaemia (prevalence 1 per 78 000[5])
- Multiple endocrine neoplasia mediated through primary hyperparathyroidism: most commonly type 1 and type 2A (combined prevalence 2-4 per 100 000[6])

*These could be considered after exclusion of the two most common causes

What is the next investigation?

Measurement of serum parathyroid hormone and repeat serum calcium

The next most useful investigation is to measure the serum parathyroid hormone concentration—to ascertain the most likely cause of the hypercalcaemia at the same time as confirming hypercalcaemia. It is important to confirm hypercalcaemia to exclude a spurious finding related to excessive tourniquet use or laboratory error. As the physiological response to hypercalcaemia is to suppress endogenous production of parathyroid hormone, a raised parathyroid hormone concentration or an inappropriately "normal" concentration is essentially diagnostic of primary hyperparathyroidism,[7] whereas a reduced concentration indicates some other cause of hypercalcaemia. The routine parathyroid hormone assay is for full length or intact parathyroid hormone and has a specificity of >99%.[8]

If parathyroid hormone concentration is raised or normal

If renal function is normal, primary hyperparathyroidism is the most likely cause of hypercalcaemia,[3] though a urinary 24 hour calcium excretion may be needed to exclude familial hypocalciuric hypercalcaemia. Referral to a specialist is recommended at this stage, for confirmation of the diagnosis and more definitive management.

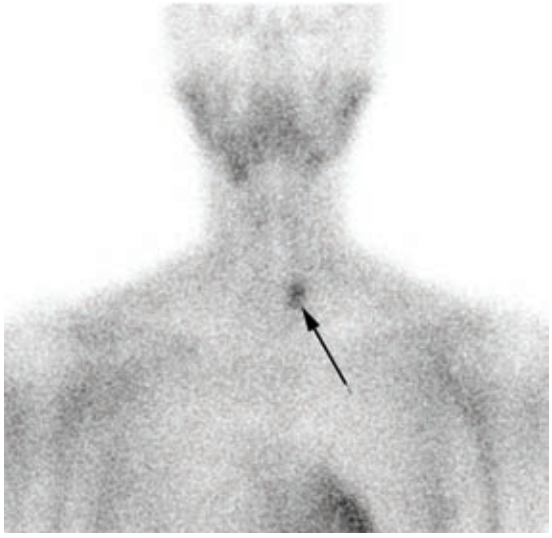

Fig 1 | Delayed, four hour, static sestamibi image of parathyroid adenoma showing differential washout of adenoma (arrow) compared with the rest of the thyroid gland

Urinary 24 hour calcium—A normal (<7.5 mmol/day) or raised value is typical in primary hyperparathyroidism, and a raised value increases the risk of renal calculi. Markedly low urinary calcium excretion may indicate familial hypocalciuric hypercalcaemia, an autosomal dominant condition presenting with hypercalcaemia.[5] This diagnosis should be considered especially in younger patients and those with a family history of hypercalcaemia as identification prevents unnecessary and unhelpful parathyroid surgery and has implications for other family members.

If parathyroid hormone concentration is low

Suppression of parathyroid hormone is physiological with hypercalcaemia, and a low concentration excludes primary hyperparathyroidism. Other causes need to be investigated, including malignancy (box). Hypercalcaemia of malignancy can either be secondary to paraneoplastic syndromes or be bony metastases, and further investigation should be guided by a careful history and examination. Some cancers (such as breast cancer) are more likely to metastasise to bone, whereas others are more likely to present with a paraneoplastic syndrome (such as squamous cell cancers of various organs).

Radionuclide bone scan—If metastatic bone disease is suspected, a whole body radionuclide bone scan is useful. It has a sensitivity of 77% and a specificity of 96% for detecting bone metastases.[9]

Calcidiol testing

Raised concentrations of calcidiol (also known as 25-hydroxyvitamin D) may indicate vitamin D toxicity. Very high concentrations (>150 nmol/l) warrant attention to identify and remove exogenous sources of vitamin D. Measurement of 1,25-dihydroxycholecalciferol (a form of calcitriol) concentration is not required except to exclude a raised concentration alone, which may indicate granulomatous conditions such as sarcoidosis.

Thyroid function tests

If thyrotoxicosis is the cause of hypercalcaemia, it is likely to be clinically apparent. Thyroid function tests (especially suppressed thyroid stimulating hormone) are necessary to confirm the diagnosis.

Renal ultrasonography

Renal ultrasonography showed a small left renal calculus. Primary hyperparathyroidism is associated with an increased incidence of renal calculi (15-20% of all patients), which is an indication for parathyroid surgery; renal ultrasonography may also identify asymptomatic stones. Renal ultrasonography has a sensitivity of 64% and a specificity of >90% for detecting renal calculi.[10]

Bone mineral density

Bone mineral density showed that her T scores (the patient's values compared with those of young, healthy individuals) were −2.3 in the lumbar spine and −2.4 in the proximal femur; the corresponding Z scores (the patient's values compared with those of individuals matched for age, sex, and weight) were −1.8 and −2.0. These values indicate osteopenia but exclude osteoporosis—primary hyperparathyroidism is a cause of secondary osteoporosis, as high parathyroid hormone concentrations increase bone turnover and thus loss of bone mass. Expert consensus is that bone deficit is an indication for parathyroid surgery. Bone deficit is considered to be a T score of −2.5 or lower for perimenopausal or post-menopausal women and for men aged 50 years or over, and a Z score of −2.5 or lower for premenopausal women and for men aged under 50 years.[11]

Parathyroid sestamibi scan

A parathyroid sestamibi scan with single photon emission computed tomography and ultrasonography of the neck located a left inferior parathyroid adenoma (figs 1 and 2), measuring 2.3 mm×1.3 mm. (Parathyroid sestamibi scanning is a functional study to visualise abnormal parathyroid tissue and to identify and localise an adenoma.[12 13]) Single photon emission computed tomography is a technique in nuclear medicine that provides additional three dimensional information. In 80-90% of cases of primary hyperparathyroidism a single adenoma is implicated.[3] A neck ultrasound scan

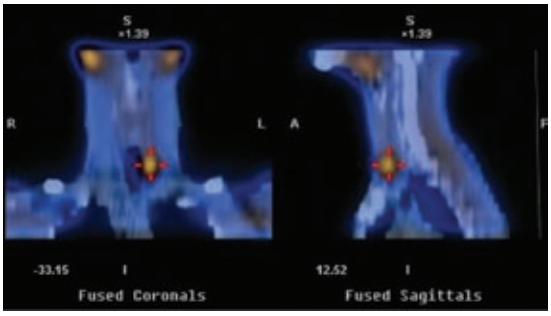

Fig 2 | Fused SPECT-CT (fused single photon emission computed tomography and normal computed tomography) images of parathyroid adenoma. Such scans can improve spatial resolution, aiding tumour localisation and planning for surgery

LEARNING POINTS

Hypercalcaemia is often asymptomatic—the classic symptoms of abdominal pain, renal calculi, and mood changes are often absent

The most important tests to order before referral include a measurement of serum parathyroid hormone concentration and a repeat serum calcium concentration

Primary hyperparathyroidism is the commonest cause of hypercalcaemia in the community

Serum parathyroid hormone values are suppressed in most other causes of hypercalcaemia, such as hypercalcaemia of malignancy and vitamin D toxicity

Presence of complications (such as low bone mineral density and renal calculi) and severity of hypercalcaemia underpin decisions about surgery

combined with the sestamibi scan in the preoperative investigations will guide the surgical approach.[14] However, neither a sestamibi scan nor an ultrasound scan will provide a clear diagnosis in every individual. Use of both investigations has a sensitivity of 81% and a specificity of 87%, providing a clear location in around 95% of primary hyperparathyroidism when performed in centres specialising in parathyroid imaging and surgery.[15]

Outcome

In this patient, serum parathyroid hormone concentration was 9.5 (reference range 1.0-7.0) pmol/l and the urinary 24 hour calcium concentration was normal. Her general practitioner, assuming that the diagnosis was most likely to be hyperparathyroidism, referred her to an endocrinologist, who undertook further tests to confirm the diagnosis, elucidate complications of hyperparathyroidism, and localise the parathyroid lesion.

Treatment

As noted, this patient's mild hypercalcaemia did not require rehydration. With more severe hypercalcaemia (>3 mmol/l), rehydration is required, usually with intravenous saline; this generally reduces the serum calcium concentration by up to 0.5 mmol/l. In more severe cases, intravenous bisphosphonates such as disodium pamidronate or zoledronic acid may be helpful. These reduce bone resorption by reducing the calcium load but do not alter the high renal calcium reabsorption.

Mild hypercalcaemia may remain stable over many years, not requiring treatment. The decision for surgical management depends on[11]:

- Severity of hypercalcaemia (>0.25 mmol/l above the upper limits of normal)
- Renal calculi or damage (as creatinine clearance reduced)
- Low or decreasing bone mineral density
- Young age (<50 years) with potential long follow-up
- Difficulty with follow-up, and presence of comorbidities.

As this patient had a renal calculus, she had minimally invasive parathyroid surgery to remove the adenoma. She had an uneventful recovery with normalisation of serum calcium concentrations.

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1 Silverberg SJ, Bilezikian JP. Primary hyperparathyroidism. In: Rosen CJ. Primer on the metabolic bone diseases and disorders of bone metabolism. 7th ed. ASBMR, 2008:302-6.
2 Shepard MM, Smith JW 3rd. Hypercalcaemia. *Am J Med Sci* 2007;334:381-5.
3 Rodgers SE, Lew JI, Solorzano CC. Primary hyperparathyroidism. *Curr Opin Oncol* 2008;20:52-8.
4 Wermers RA, Kearns AE, Jenkins GD, Melton LJ. Incidence and clinical spectrum of thiazide-associated hypercalcaemia. *Am J Med* 2007;120:911-5.
5 Hinnie J, Bell E, McKillop E, Gallacher S. The prevalence of familial hypocalciuric hypocalcemia. *Calcif Tissue Int* 2001;68:216-8.
6 Brandi ML, Gagel RF, Angeli A, Bilezikian JP, Beck-Peccoz P, Bordi C, et al. Guidelines for the diagnosis and therapy of MEN type 1 and type 2. *JCEM* 2001;86:5658-71.
7 Bilezikian JP, Brandi ML, Rubin M, Silverberg SJ. Primary hyperparathyroidism: new concepts in clinical, densitometric and biochemical features. *J Intern Med* 2005;257:6-17.
8 National Committee for Clinical Laboratory Standards. Interference testing in clinical chemistry. Proposed guideline. NCCLS EP7-P. Wayne, PA: NCCLS, 1986.
9 Sadik M, Suurkula M, Hoglund P, Jarund A, Edenbrandt L. Quality of planar whole-body bone scan interpretations—a nationwide survey. *Eur J Nucl Med Mol Imaging* 2008;35:1464-72.
10 Sinclair D, Wilson S, Toi A, Greenspan L. The evaluation os suspected renal colic: ultrasound versus excretory urography. *Ann Emerg Med* 1989;18:556-9.
11 Bilezikian JP, Khan AA, Potts JT. Guidelines for the management of asymptomatic primary hyperparathyroidism: summary statement from the third international workshop. *JCEM* 2009;94:335-9.
12 Johnston LB, Carroll MJ, Britton KE, Lowe DG, Shand W, Besser GM, et al. The accuracy of parathyroid gland localisation in primary hyperparathyroidism using sestamibi radionuclide imaging. *JCEM* 1996;81:346-52.
13 Gordon L, Burkhalter W, Mah E. Dual-phase Tc-sestamibi imaging: its utility in parathyroid hyperplasia and use of immediate/delayed ratios to improve diagnosis of hyperparathyroidism. *J Nucl Med Technol* 2002;30:179-84.
14 Kamaya A, Quon A, Jeffrey RB. Sonography of the abnormal parathyroid gland. *Ultrasound quarterly* 2006;22:253-62.
15 Sukan A, Reyhan M, Aydin M, Yapar AF, Sert Y, Canpolat T, et al. Preoperative evaluation of hyperparathyroidism: the role of dual-phase parathyroid scintigraphy and ultrasound imaging. *Ann Nucl Med* 2008;22:123-31.

Interactive case report

A woman with acute myelopathy in pregnancy

This case was described on 14 and 21 November (*BMJ* 2009;339:b3862, b4025). Debate on the management of this real patient continues on bmj.com (www.bmj.com/cgi/eletters/339/nov19_2/b4025). On 12 December we will publish the outcome of the case together with commentaries on the issues raised by the management and online discussion from the patient and relevant experts.

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QUALITY IMPROVEMENT REPORT

Improving quality in resource poor settings: observational study from rural Rwanda

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Abstract

Problem Hospitals in rural Africa, such as in Rwanda, often lack electricity, supplies, and staff. In our setting, basic care processes, such as monitoring vital signs, giving drugs, and laboratory testing, were performed unreliably, resulting in delays in treatment due to lack of information needed for clinical decision making

Design Simple quality improvement tools, including plan-do-study-act cycles and process maps, were used to improve system level processes in a stepwise fashion; resources were augmented where necessary.

Setting 50 bed district hospital in rural Rwanda.

Measurement of improvement Three key indicators (percentage of vital signs taken by 9 am, drugs given as prescribed, and laboratory tests performed and documented) were tracked daily. Data were collected from a random sample of 25 charts from six inpatient wards.

Strategy for change Our intervention had two components: staff education on quality improvement and routine care processes, and stepwise implementation of system level interventions. Real time performance data were reported to staff daily, with a goal of 95% performance for each indicator within two weeks. A Rwandan quality improvement team was trained to run the hospital's quality improvement initiatives.

Effects pf changes Within two weeks, all indicators achieved the 95% goal. The data for the three objectives were analysed by using time series analysis. Progress was compared against time by using run chart rules for statistical significance of improvement, showing significant improvement for all indicators. Doctors and nurses subjectively reported improved patient care and higher staff morale.

Lessons learnt Four lessons are highlighted: making data visible and using it to inform subsequent interventions can promote change in resource poor settings; improvements can be made in advance of resource inputs, but sustained change in resource poor settings requires additional resources; local leadership is essential for success; and early successes were crucial for encouraging staff and motivating buy-in.

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Introduction

Financial and material needs[1 2] and shortages of human resources[3 4] have a substantial impact on health care of developing nations, and on carrying out routine care processes. Limited data have been published on quality improvement efforts in resource poor settings, and there is scepticism about quality improvement approaches in settings of severe resource constraints.[5]

We determined whether using quality improvement methods could improve the quality of care provided at one district hospital in Rwanda.

Setting

Kirehe District Hospital is part of a collaboration among the non-profit Partners In Health, the Clinton Foundation, and the Rwandan Ministry of Health. The 50 bed hospital has six wards (women, men, paediatrics, malnutrition, and maternity, and an isolation ward for tuberculosis patients) and serves a catchment area of 292 000 people, predominantly subsistence farmers. At the beginning of this project, the hospital had 37 nurses and four doctors, with a patient:nurse ratio of about 10:1.

Outline of problem

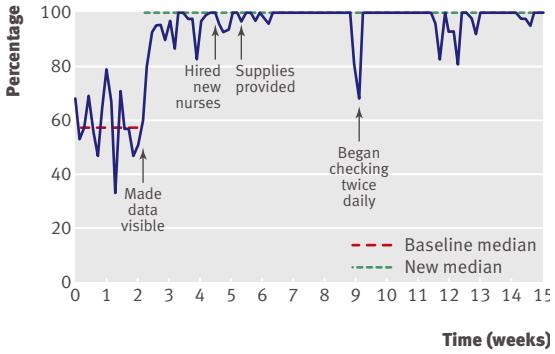
At Kirehe Hospital we were unable to monitor vital signs consistently, give drugs in a timely fashion, and carry out requested laboratory tests promptly. These gaps in basic care led to delays in diagnosis and treatment. They were selected as key process targets through informal discussion.

Key improvement measures

Our aim was to reach 95% (in keeping with level II reliability[6]) for each goal—vital signs taken by 9 am, drugs given as prescribed, and laboratory tests completed and recorded in the chart by 9 am the morning after they were ordered—for five continuous days within two weeks of the start of the project. We chose this performance level to force a focus on system changes, not just on increased individual effort.

Data collection

Baseline data were collected on each of the three indicators for two weeks before the start of the initiative. Every weekday morning at 9 am, the nurse in charge of quality improvement reviewed a sample of 25 charts equally distributed across all six wards. This method was continued throughout the initiative and data were collected between October 2007 and March 2008. The results were validated by a second team member who accompanied the quality improvement nurse during chart rounds on average once a month. Additionally, a convenience sample of patients was briefly interviewed at least weekly to confirm that vital signs had been performed properly and drugs given properly, and not simply recorded in the chart.



Percentage of vital signs monitored. Baseline median was calculated from 14 days of baseline data before interventions were implemented; new median was calculated for new system according to run chart rules (consistent improvement for eight straight data points)

Analysis and interpretation

The baseline data highlighted important gaps in performance. The daily reporting of data throughout the initiative prompted routine discussions of failures with the staff, allowing for identification of obstacles.

Strategy for change

The intervention was based on Nolan et al's Model for Improvement.[7] This model emphasises planning the intervention in precise detail, implementing it on a small scale, studying the results, and then expanding, revising, or abandoning the intervention accordingly through plan-do-study-act cycles. The quality improvement team consisted of a Rwandan nurse and doctor, the hospital nursing director, the hospital medical director, and two foreign staff members.

The initiative had two primary components. The first focused on educating hospital staff about quality improvement and the importance of the three selected care processes. The second was a series of plan-do-study-act cycles, implementing interventions in a stepwise fashion while tracking selected indicators. Data were made visible to the staff on large run charts posted in the staff meeting room. The previous day's data were reviewed in the morning staff meeting, followed by a discussion of failures led by the quality improvement nurse. One key element of the interventions was adding both extra staff and equipment as necessary.

Vital signs

Staff discussions of performance data identified two resource gaps. The first was a lack of equipment necessary for monitoring vital signs–the hospital had only one functioning blood pressure cuff and three thermometers. One month into the project, new equipment (three blood pressure cuffs, six thermometers, and an oxygen saturation monitor with adult and paediatric probes) was purchased. The second was the high patient:nurse ratios. At the start of the project, there were 37 nurses on staff—one nurse per ward per shift. During the second month of this project, eight additional nurses were hired, allowing for two nurses per ward on the day shift and an additional nurse in the hospital at night.

Giving drugs

Daily publication of data to the staff and one education session on the importance of timely administration of drugs were the primary interventions. After the eight nurses were hired (about 20 days after the start of the project) improved staffing ratios made it possible for the nurses to give drugs at scheduled times.

Laboratory tests

The third objective—laboratory tests performed and recorded by 9 am the morning after they were ordered—started about a month after the initial two objectives. After initially making the data visible to all staff, we introduced a new improvement tool: process mapping. We created a simple process map, and a facilitated discussion determined the reasons for failure at each step in the process. For each failure, the team identified an idea for improvement.

The process map identified two major obstacles. Firstly, results were not being retrieved from the laboratory in a timely way, largely because it was difficult to locate the results. This problem was addressed by placing a box in the laboratory for results sheets for each ward. Nurses depositing samples at the lab noted the ward name on each sample.

Secondly, process mapping identified the human resource gap as a major obstacle to improvement. Having more nurses allowed one nurse to go on ward rounds while the other nurse gave drugs and collected samples for laboratory testing.

Effects of change

All three improvement projects resulted in rapid, substantial improvements, reaching the goal of 95% for five continuous days within two weeks. At baseline the median performance for vital signs was 57%, giving drugs 63%, and laboratory testing and documentation 46%. Making the data visible resulted in early improvement in each project, but the results were not consistently at 100% until shortfalls of equipment and staff were remedied. Shortly after these additions, data were routinely at 100% for each of the three improvement indicators. These improvements, and corresponding interventions, are described on the annotated run chart for monitoring of vital signs (figure); for charts showing drug prescribing and laboratory tests see bmj.com.

Analysis

The data for each of the three interventions were analysed by using time series analysis. Progress was compared against time by using run chart rules for statistical significance of improvement.[8] Medians

were calculated for baseline data. A new median was calculated when the run chart rule reached a significant change. At this point we considered that a new system was now in place.

Lessons learnt

Four important lessons emerge that may be relevant to resource poor settings.

Shed light on performance

Making data visible and using them as a tool to make decisions about subsequent interventions and resource inputs contributed greatly to the initiative's success. This simple intervention helped build team spirit by eliminating the blaming and competitive aspect of previous quality initiatives.

Increase available resources

In resource poor settings quality is often limited by gaps in resources that cannot be overcome by hard work and system improvements alone. Resource inputs must also be augmented. At the start of the site collaboration in 2005, there was little care to improve as a result of shortages in medicines, infrastructure, and human resources. In this project, human resources were widely identified as the greatest need. Basic quality improvement tools allowed existing gaps to be identified precisely, in order to add resources most efficiently. The real costs of this work are considerable. Eight new nurses were hired, and new materials were purchased, costing about $41 000 (£25 200; €28 700) per year.

Train local leaders

Local leadership is essential when improvement work is undertaken in a crosscultural setting.[9 10] The leadership of a Rwandan nurse and doctor was essential for this project's success. They were able to encourage and motivate their colleagues more effectively, and their experience was invaluable as the team planned the interventions.

Show early success

Early successes in quality improvement are crucial for encouraging staff.[11] This principle is no less true in resource poor settings.

Limitations

Verifiability

We were not able to verify the data on drugs given to patients written in the charts, and we were only able to validate it by asking a limited number of patients if and when they had received their drugs.

Timeframe

The study had a limited timeframe. Since completion, performance has been monitored while real-time data reporting to staff has been scaled back. Review of this subsequent performance data will show whether the interventions can promote sustainable change.

Use of process measures

Process measures instead of outcome measures were evaluated, in part because of the additional cost of measurement required in a resource constrained setting. Further research is needed to quantify the impact on outcome measures, such as length of stay, morbidity, and mortality.

Conclusions

Quality improvement methodology has been widely used in resource rich settings to improve the quality of health care at a system level by improving efficiency of existing systems and maximising current resource inputs. We used the same methodology in a rural district hospital in a resource poor setting and showed similar improvements. A key difference was the systematic addition of resources to fill existing gaps. When plan-do-study-act cycles and process maps are used to identify gaps, new resources can be added most efficiently. To improve the quality of care in resource poor settings, system development and increased resources must go hand in hand; both are necessary for continued success.

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1 World Health Organization. *The world health report 1995: bridging the gaps*. 1995. www.who.int/whr/1995/en/index.html.
2 World Bank. *The millennium development goals for health: rising to the challenges*. 2004. www.hlfhealthmdgs.org/documents.asp
3 World Health Organization. *High level forum on the health MDGs. Addressing Africa's health workforce crisis: an avenue for action. December 2004*. www.hrhresourcecenter.org/node/1069.
4 Chen L, Evans T, Anand S, Boufford JI, Brown H, Chowdhury M, et al. Human resources for health: overcoming the crisis. *Lancet* 2004;364:1984-90.
5 Abdallah H, Chernobrovkina O, Korotkova A, Massoud R, Burkhalter B. *Improving the quality of care for women with pregnancy-induced hypertension reduces costs in Tver, Russia*. Bethesda: Quality Insurance Project, 2002. www.qaproject.org/pubs/PDFs/pihtver.pdf.
6 Nolan TW, Resar R, Haraden C, Griffin FA. *Improving the reliability of health care. IHI innovation series white paper*. Boston, MA: Institute for Healthcare Improvement, 2004. www.ihi.org/IHI/Results/WhitePapers/ImprovingtheReliabilityofHealthCare.htm
7 Langley GL, Nolan KM, Nolan TW, Norman CL, Provost LP. *The improvement guide: a practical approach to enhancing organizational performance*. San Francisco: Jossey-Bass, 1996.
8 Carey RG. *Improving healthcare with control charts: basic and advanced SPC methods and case studies*. Milwaukee, WI: ASQ Quality Press, 2003.
9 Reinertsen JL, Gosfield AG, Rupp W, Whittington JW. *Engaging physicians in a shared quality agenda. IHI innovation series white paper*. Cambridge, MA: Institute for Healthcare Improvement, 2007. www.ihi.org/IHI/Results/WhitePapers/EngagingPhysiciansWhitePaper.htm
10 Mohammadi SM, Mohammadi SF, Hedges JR, Zohrabi M, Ameli O. Introduction of a quality improvement program in a children's hospital in Tehran: design, implementation, evaluation and lessons learned. *Int J Qual Health Care* 2007;19:237-43.
11 Brown LD. Lessons learned in institutionalization of quality assurance programs: an international perspective. *Int J Qual Health Care* 1995;7:419-25.

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